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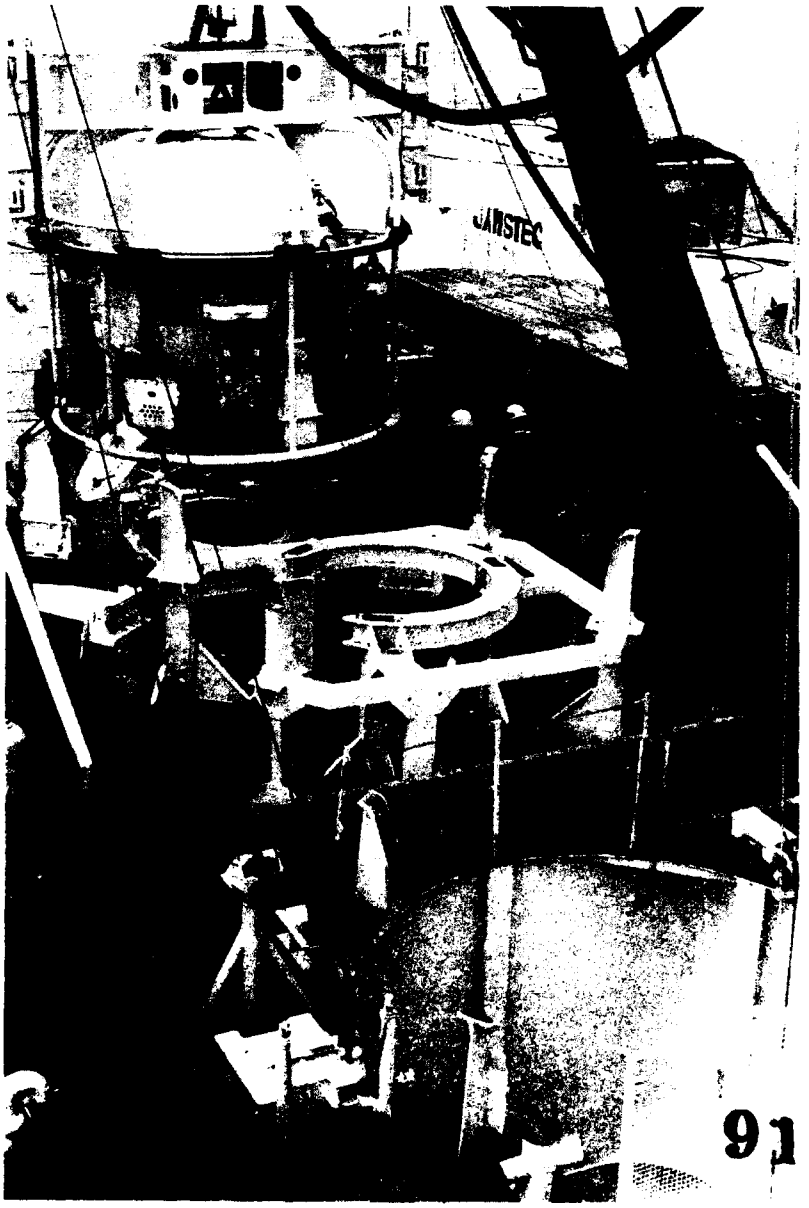

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This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONRASIA, with certain reports also being contributed by visiting stateside scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work, considered to be of special interest. This publication is approved for official dissemination of technical and scientific information of interest to the Defense research community and the scientific community at large. It is available free of charge to approved members of the DOD scientific community. Send written request describing DOD affiliation to: Director, Office of Naval Research, Asian Office, APO San Francisco 96503-0007.

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OCEAN SCIENCES
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Cover: A submersible decompression chamber being positioned for lowering through the center well of the *Kaiyo*. See the article on page 139 for a description of this saturation diving research vessel. Photo courtesy of Neal Naito.

SIBRIEFs

Scientific Information Briefs

INDO-U.S. WORKSHOP ON SPECTRAL ANALYSIS IN ONE OR TWO DIMENSIONS

This workshop was held to enhance Indo-U.S. science cooperation in the area of spectral analysis. The underlying theme of the workshop was to capture recent developments occurring in the various facets of spectral analysis such as array processing, signal processing, and image processing and resulting implications and implementations of ensuing techniques, algorithms, and architectures. Some 55 papers were presented; about 35 were by authors from India and the remainder were from the United States. There were about 150 participants including a sizable number of graduate students from the Indian Institute of Technology. The Indian authors were primarily from the Indian Institutes of Technology and Science, but several government and industrial laboratories, such as the Naval Physical and Oceanographic Laboratory, Cochin, and the Central Research Laboratory of Bharat Electronics, were represented.

The presentations were organized into six sessions, the border lines of which were flexible, as the meeting structure was based on a single session and discussions were based on questions raised by the participants. Spatial spectrum analysis, or the estimation of the directions of arrival (DOA) of multiple plane waves from data arriving at an array of sensors, was the subject of the first session titled "Spectral Analysis with Multiple Nodes." The papers in this session included some new and thought-provoking approaches to problems relevant to array processing. It was interesting to see the formulation of the sensor array processing problem in terms of artificial neural networks which, in recent years, have fashioned themselves into many diverse application domains. Other papers dealt with the modern array processing problem, such as the use of beam space processing for computational efficiency and robustness, broadband DOA estimation, coherent ESPRIT, DOA estimation with maneuvering arrays, source localization in shallow waters, and others.

Professor V.U. Reddy of the Indian Institute of Science (IIS), Bangalore, addressed the problem of direction finding and beamforming in the presence of multipath for wideband signals. The degradation due to multipath was represented in terms of the reduction of the wideband rank of the sources as defined by Professor Kevin Buckley of the University of Minnesota. For linear arrays, it was shown that spatial smoothing recovers the effective rank.

One of the limitations of the ESPRIT algorithm is that it is not applicable to the case for coherent sources. Drs. B. Chandna and S. Prasad of the Indian Institute of Technology (IIT), New Delhi, presented a paper that showed how a special form of spatial smoothing may be used as a preprocessor to remove the rank degeneracy of the ESPRIT signal-subspace. This approach is useful for linear uniform arrays.

Source localization in shallow water using signal-subspace methods is a particularly difficult problem. Professor Naidu's group at IIS Bangalore has been actively pursuing research on this problem. Krishna and Naidu presented a paper on the subject. Their algorithm is called Multi-image Subspace Algorithm and uses the images of the primary sound source on the multipath components to estimate the location of the source.

Dr. Paulraj of Bharat Electronics presented an interesting paper that uses the idea of focusing, devised by Professor Kaveh of the University of Minnesota for wideband arrays, to align the subspaces generated by measurements by a maneuvering array platform. This alignment gives the possibility of averaging correlation matrices from several stationary segments of the data to improve the accuracy of the localization method.

The session on "Nonlinear and Adaptive Techniques" contained a very significant and useful review paper on the importance of and techniques associated with the use of higher order statistics in signal processing. Higher order statistics are assuming an increasingly important role in applications such as parameter estimation in non-Gaussian environments and nonminimum phase conditions as encountered in applications like seismic deconvolution. Other papers in this section dealt with a mixture of topics on adaptive filtering and control, including some applications to robot dynamics.

The next session on "Multidimensional Systems" dealt with diverse issues and problems arising in image processing and computer vision. The topics included some fundamental modeling and algorithmic issues in image estimation, texture classification, computer vision, and holographic imaging from sensor array data.

Some interesting problems arising in the modeling and processing of time series and array data were the topics of interest in the session on "Spectral Estimation and Detection." The issues addressed included investigations into high resolution spectrum estimation based on time series and eigenstructure models, detection of the number of signals in the incoming data, and the robust estimation of the AR parameters of time series. One highlight of this session was a paper by Professor C. Radhakrishan Rao. Starting from statistical assumptions he showed the derivation

of such algorithms as MUSIC, ROOT-MUSIC, etc. and provided a refreshing insight into and a welcome overview of practically all the work in progress in array processing. Professor Rao's presence and involvement elevated the quality of discussions in all sessions.

The talks in the "Parallel Processing" session represented an assortment of topics illustrating the many faceted nature of current research in this important area. There were interesting new solutions to parallel implementations of signal processing problems, such as the solution of Toeplitz system of equations and computations for image processing, etc.

The final session on "Filtering Techniques" dealt with theoretical issues concerned with both the classical digital filter design problem as well as with some of the burning issues related to numerical robustness of digital filters and adaptive filtering.

The workshop was an unqualified success. It proved as expected that Indian scientists and engineers are engaged in cutting-edge research in all aspects of spectrum analysis and its many facets in array processing, signal processing, and image processing.--*Rabinder N. Madan, ONR*

* * * * *

TOKYO UNIVERSITY OF AGRICULTURE AND TECHNOLOGY, MATERIAL SYSTEMS ENGINEERING LABORATORY

Molecular Designing of New Quadratic Nonlinear Optical Materials

Lambda (Λ) Type Molecules. Second-order optical nonlinearity is observed only in noncentrosymmetric crystals, but the majority of organic molecules crystallize in a centrosymmetric structure. A novel concept of introducing noncentrosymmetry in organic molecules has been discovered. Our molecular orbital (MO) calculation by the MOPAC AM1 method demonstrated that molecules, such as methanediamines, in which two aniline derivatives are bonded together via a methylene bridge ($-CH_2-$) form lambda (Λ) type conformations. The Λ type molecules prefer to crystallize into noncentrosymmetric structure because they can easily stack along the same direction. This type of crystal is good for bulk phase matching because the angle of Λ molecules can be controlled by introducing a bulky side chain to the benzene ring of methanediamine. The largest molecular hyperpolarizability tensor, β_{ijk}, effectively contributes to the nonlinear optical coefficient. All the methanediamines synthesized in our laboratory are second harmonic generation (SHG) active.

Spontaneous Formation of Noncentrosymmetric Structure by Mixing (Composites). Although p–nitroaniline molecules exhibit large second order hyperpolarizability but are centrosymmetric in the crystalline state, second-order optical effects are not observed. A novel approach to obtaining the highly aligned p-nitroaniline (p-NA) crystals in a poly(ε-caprolactone) (PCL) matrix has been investigated. A p-NA system shows a very strong SHG signal on simple mixing because of the spontaneous formation of acentric crystals. The SHG activity is, for example, 2.6 times larger than that of 2-methyl-p-nitro aniline (MNA) in powder tests. The spontaneous asymmetric crystallization process induced on mixing is of great importance to attaining large optical nonlinearity in p-NA systems. This new approach has been extended to other p-NA/polymer systems.

New Moving Wall Langmuir-Blodgett (LB) Trough for Viscous and Stiff Monolayers

In an ordinary LB trough, generally two major problems are encountered during the film deposition process: (1) the monolayer is inhomogeneously compressed due to the friction between monolayer edges and the trough, and (2) the monolayer flows with shears from all sides of the trough toward the solid substrate to fill a hole developed during deposition. Therefore, the complex moving behavior of the monolayer leads to a different molecular orientation on the solid substrate than that of the originally compressed monolayer on the water surface. In order to overcome these problems, we have designed a new moving wall type LB trough in which the width of the trough is the same as that of the solid substrate and the side walls move simultaneously with the barrier, pushing the monolayer on the water surface. These advanced features assist in preventing the complicated flows of the monolayer and also reduce the friction. This new LB trough is also especially useful for rigid monolayers, e.g., lanthanum stearate and aluminum stearate, which do not form LB films using ordinary troughs. An additional feature equipped with the moving wall trough is the "zone-heating mechanism." The x-ray diffraction patterns of the zone-heat-treated films are sharper and half-widths are narrower, which indicates that the multilayer structure obtained by using this new technique is more ordered compared to the conventional method. This new moving wall LB trough has already been commercialized by the Nippon Lasers and Electronics (NLE) Company in Japan and overseas.

A Novel Approach for Synthesizing Electrically Conducting Polymers

Chemical Vapor Deposition (CVD) of Transparent Conducting Polymers. In our laboratory, a novel method of preparing highly transparent and conducting polypyrrole composite films has been developed. A poly(vinyl alcohol) (PVA) film containing ferric chloride (oxidant) instantaneously becomes conducting on exposure to pyrrole vapors. The polymerization proceeds through the

oxidation of pyrrole by $FeCl_3$ salt diffused in the PVA polymer matrix. Highly transparent and conducting polypyrrole composite films can be obtained by monitoring the $FeCl_3$ concentration and polymerization time. This CVD process improves the transparency without affecting the conductivity compared with the electrochemical polymerization technique. The ease of fabrication as well as the simplicity of the process suggest that this new CVD method would be an efficient technique for obtaining economically transparent conducting polymers on an industrial scale.

Novel Piezoelectric Polymers

Optimization of Piezoelectricity in Poly(Vinylidene Fluoride) (PVDF) by the Control of Superstructure. Zone-drawing and zone-annealing techniques are used in making polymer fibers of high modulus and high strength. In order to improve mechanical strength and electret properties, a new electret apparatus has been developed. This new electret preparation method consists of simultaneous zone-drawing and poling and can apply the field to the necking zone where the phase transition of PVDF form II to form I occurs. A more perfect dipole alignment is achieved for the simultaneously stretched and poled PVDF in a zone-annealing process. The piezoelectric constant of PVDF obtained by this novel technique is 40 x 10^{-12} C/N, much larger than that obtained by other methods. This technique could be applicable to a continuous process of making polymer electret on a large scale.

Copolymers of Vinylidene Cyanide (VDCN) and Vinyl Acetate (VAc)--A New Class of Piezoelectric Materials. The new amorphous and alternating copolymers of VDCN and VAc were first developed in our laboratory. These copolymers have large C-C≡N dipole moment arising from the polar bonding between the carbon and cyanide group. Piezoelectricity in the VDCN/VAc copolymer originates from the rotation of the C≡N dipoles, and the piezoelectric constant of the copolymer is within the range of PVDF. The copolymers show better thermal stability (170 °C) than PVDF polymers. Also the copolymer has low acoustic impedance and well matches acoustically to human body tissue and water; hence energy transfer is possible. The highly transparent and piezoelectric copolymers can be used in a wide variety of electronic applications. A prototype transparent loudspeaker has been developed by coupling together the highly transparent piezoelectric VDCN/VAc copolymers and transparent conducting polypyrrole films. Applications of these novel piezoelectric copolymers in computer technology, display devices, etc. have been explored.—*Seizo Miyata, Tokyo University of Agriculture and Technology*

* * * * *

TSUKUBA FERMENTATION INSTITUTE

During a visit to the Tsukuba Fermentation Institute, I discussed current research projects with two scientists, Dr. Yasuo Asada, head of the Molecular Bioenergetics Division, and Dr. Kiyoshi Takeda, head of the Chemical Ecology Division.

In the Molecular Bioenergetics Division, research is focused on studying different aspects of photosynthesis, such as basic photochemistry and the photophysics of the process, especially electron flow and the carriers involved. The ultimate goal of this research, however, is to develop novel technologies such as synthetic photosynthesis.

Dr. Asada's primary interests are in the production of hydrogen by different photosynthetic organisms. At present he is working on cyanobacteria, especially *Spirulina*, and nonsulfur photosynthetic bacteria such as *Rhodobacter sphaeroides* and *Clostridium butyricum*. *Spirulina* can grow photosynthetically; however, in the dark, under anaerobic conditions, they release hydrogen at the expense of their stored carbohydrates. The properties of the hydrogenase and the electron flow from the starch metabolism are being studied.

Drs. Jun Miyake and M. Hara have isolated chromatophores from the photosynthetic bacteria *Rhodopseudomonas* and were able to produce layered, dried membranes of these. The dried films retained their original spectral properties and responded to light absorption by producing electrical transients. The amplitude and duration of these electrical transients could be altered by incorporating electron donors or carriers into the films. By linking biotin to the vesicles and incorporating avidin in the membranes they succeeded in producing oriented asymmetric films capable of generating the charge separation. At present they are dissecting the process by incorporating chromatophores from different bacterial strains or mutants to determine the role of the different components of the chromatophore. To divert and use the photopumped electrons of these membranes, they are planning to incorporate other electron carriers and donors across these asymmetrical membranes. Such membranes could serve as models for photosensitive devices.

Research in the Chemical Ecology Division is currently focused on the degradation of both natural and artificial polymers. Dr. Takeda's laboratory is studying the degradation of rubber. They isolated an actinomycete, *Nocardia sp.*, which grows on natural rubber, as the sole carbon source. Highly vulcanized as well as unvulcanized rubbers were degraded by this organism. Oligomers with molecular weights of 10^3 and 10^4 accumulated during the microbial growth on the latex.

More recently they isolated a rubber-degrading bacterium, *Xanthomonas sp.*, which is also an efficient digester of natural latex. From cultures of this bacterium grown on latex, it was possible to isolate extracellular crude enzyme preparations capable of degrading natural polymers. They are purifying and fractionating the extracellular enzymes to study the steps

involved in the degradation of these isoprenoid polymers.

Dr. Tokiwa is synthesizing biodegradable polymers. Previously he found that aliphatic polyesters could be hydrolyzed by various lipases, but such polymers by themselves have low melting points and are not suitable for many applications. At present he is attempting to produce copolymers from copolymers of polyester that are interspersed with polyamide sections in the molecule. The abundance of polyester bonds should make such polymers degradable by lipases, while their physical properties are improved by the amide bonding in the polymer chain. Among the copolymers they produced, they found an inverse relationship between the melting temperature of the polymer and its enzymatic degradability. I was shown a large assortment of products made up of such copolymers. How readily these products are degraded in landfills is being measured. One of the questions we discussed was the standardization of the testing and definition of "biodegradation." Apparently this is a subject of active discussion in this field. This fall an international meeting in Tokyo will further consider this question.—*Aharon Gibor, ONRASIA*

* * * * *

THE ADVANCED TELECOMMUNICATION RESEARCH INSTITUTE (ATR)

ATR was organized in 1986 with a combination of government and private money to: (1) plan and promote basic telecommunication research; (2) establish and maintain research facilities and equipment to promote integrated joint research opportunities for industrial, academic, and governmental organizations; and (3) promote international technical research and exchange of researchers. About one-third of its support is from private companies such as NTT, while the remainder is from the Government, through what is called the "Key Technology Center" program in the Ministry of International Trade and Industry (MITI). In April 1990, ATR was capitalized at slightly more than ¥51 billion, about $350,000,000. There are four major laboratories within the complex. These laboratories and their functions are as follows:

Communications Systems:

- Communications with realistic sensations, automatic three-dimensional (3–D) shape acquisition, modeling, manipulation and display
- Nonverbal interfaces, recognition of facial and eye-gaze directions, understanding gestures and hand movements, integration of visual and speech information
- Automatic generation of communication software, extraction of real intentions, use of visual language to give specifications accurately, human deliberative mechanisms in software design
- Security, cryptographic techniques for large capacity (image) communications, secure telecommunication networks

Optical and Radio Communications:

- Optical intersatellite communications, optical beam control, optical modulation/demodulation
- Advanced antennas, active array technology for mobile antennas, methods of mitigating multipath propagation problems, microwave circuit integration, signal processing
- Optical and electronic devices, growth and characterization of semiconductors with precisely controlled atomic configurations, nonlinear optical devices

Interpreting Telephony:

- Speech recognition and synthesis
- Interface between speech and language, spoken language processing, knowledge base
- Machine translation, grammar for analysis of Japanese, dialog interpretation, contextual processing

Auditory and Visual Perception:

- Basic mechanisms of visual perception, character and pattern understanding, scene analysis and understanding
- Cognitive processes for visual information, parallel computing principles, learning and motor theories of perception
- Hearing and speech perception and recognition, auditory models

ATR publishes the *ATR Journal* six times each year. Although most of the articles are in Japanese, a few are in English, and often there are enough figures, illustrations, and tables to get a sense of the topics. There are also reports whose titles (some in English) are printed in the journal. Principal ATR research areas are teleconferencing with three-dimensional images, computer security, telephone translation, kanji recognition, optical communication in space, and mobile radio communications. The Audio and Visual Perception Laboratory features a variable sound reverberatory chamber in which the sound-reflecting properties of the walls and ceiling can be continuously adjusted between full reflection and total absorption. The Interpreting Telephony Laboratory is engaged in efforts to convert spoken Japanese into spoken English via machine translation. A system has been developed that can successfully perform the conversion using a limited number of simple expressions, a known "calibrated" human speaker, and a vocabulary of about 300 words.

My own interest in ATR was specifically toward their research in parallel processing and more casually in neural

networks and graphical interfaces. My main contact there was Dr. Noboru Sonehara, in the Auditory and Visual Perception Laboratory [sonehara@atr-hr.art.co.jp], and his boss, Dr. Kazunari Nakane, who heads the Cognitive Processes Department [nakane@atr-hr.atr.co.jp]. In addition, I met with Dr. Masa-aki Sato, in the Visual Perception Laboratory; Dr. Peter Davis, who is working in optical materials; and Kelley Picket, who works for Thinking Machines and has been at ATR for about 6 months.

ATR has a Connection Machine (CM), the only one in Japan at this time, which was installed early this year. It was modified to only permit 32-bit floating point computation. I am told that new trade agreements will allow 64-bit chips to be installed. Picket, who is responsible for teaching the ATR staff how to use the machine, felt that it was slow going to get some of the Japanese scientists to pick up the ball and run with it, although Sonehara was one of his most enthusiastic users. At this time the machine is not being used as effectively as it could be and there are some internal questions about what groups are permitted access. Only a few programmers are actually using the CM, although a larger number of people are directing work by the programmers. Most of the work on the CM is related to implementing neural network models. For example, Sonehara sent me a paper of his concerning the problem of converting a digitized image containing k grey levels to one containing only black and white (k=2), so-called binary representation of a grey level image. Unfortunately, the paper did not give any details of the computational implementation. An earlier paper, using analog methods, was given by Koch [C. Koch, J. Marroquin, and A. Yuille, "Analog 'neurona' networks in early vision," in *Proc Nat Acad Sci USA* **83**, 4263-4267, (1986)]. Sonehara also has studied interpolation methods for image processing using an iterative neural network model that he also implemented on the CM.

Dr. Sato described some of his work which has general application in the area of speech synthesis. (A preprint is available from the author; "APOLONN brings us to the real world: Learning nonlinear dynamics and fluctuations in nature.") A major problem in synthetic speech is its unnaturalness, due mostly to the lack of high harmonics, short waveforms, and time dependent spectra. Sato and his colleagues are experimenting with a nonlinear network, APOLONN, in an effort to solve this problem. In the analysis of their network they are led to the mathematical problem of minimizing an energy functional whose values depend on the solution of a system of ordinary differential equations with prescribed initial conditions. The analysis is quite elegant. But, as I have now seen several times, the computer simulation of this was done from the ground up with no collaboration with a numerically trained researcher. The integration is via fixed step Euler's method and this could surely be improved. I cannot tell if such improvements would make an appreciable difference in their ability to train the network to synthesize speech.

Dr. Davis is primarily working on optical devices. He has been studying systems that can be made to behave chaotically. In his context this means that they can have many configurations by making small changes in their input. He is hoping that such devices can have applications as memories. Although the techniques are quite different, this is in the same spirit as Michael Barnsley at Georgia Tech, who wants to capture the details of an image in a few parameters and hence use them as a data compression technique. In Davis' model of the devices he is studying, there are several ordinary differential equations of "delay" or "retarded" type, wherein the time derivative of the unknown depends on the solution at some past times. I explained to Davis that there was new work on these equations, and it is possible that some of his models will be used as test cases for very new numerical solvers.

ATR is extremely well equipped, even in comparison to some of the other industrial laboratories I have visited. If anything, it seems to be top heavy with equipment and short of staff, although it is a very new facility and is still in the recruiting stage. One of their well publicized projects is to develop a "Dick Tracy" watch. As Seiko has just announced a wrist watch with pocket pager, there is plenty of interest in this research. ATR is also working on manipulation in three dimensions. An operator wears a specially instrumented glove and glasses while watching a computer screen on which a 3–D computer-generated image is displayed. The 3-D effect is via the glasses. By moving the gloved hand in free space the operator can affect the movement of various objects on the screen. Unfortunately, none of the researchers on these projects was available during my visit.

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* * * * *

ENDOCRINE BIOTECHNOLOGY AND ITS APPLICATION TO FISH CULTURE IN JAPAN

Peter M. Collins

In recent years the application of advanced biotechnology in fundamental research has clarified specific endocrine mechanisms operating in fish. The information emerging from these studies offers promise for the development of "tailor-made" strategies that will enable the manipulation of each of the component phases in the life cycle of fish. This article is based on a recent tour of selected Japanese institutions with programs focussed on fish endocrinology.

INTRODUCTION

The development of fish culture techniques provides an important augmentation of food resources in many countries on the Pacific Rim and elsewhere. However, in spite of notable achievements with the culture of certain freshwater and salmonid species, the majority of fish that reach the market are still caught in open water. In particular, attempts to culture marine fish have met with limited success. The farming of marine species is mainly confined to "grow-out" operations in which wild fry are captured and raised to marketable size.

The application of endocrinology to aquaculture has led to an improvement of traditional methods of fish culture. However, the endocrine strategies currently employed to promote maturation and to induce spawning in fish are still based to a great extent on the empirical application of hormone regimens developed for use in various clinical situations in Man. In recent years the application of advanced biotechnology in fundamental research has clarified specific endocrine mechanisms operating in fish. The information emerging from these studies offers rare promise for the development of "tailor-made" strategies that will enable the manipulation of each of the component phases in the life cycle of fish (Figure 1).

This report is based on a recent tour of selected institutions in Japan. It is not possible to cover the complete spectrum of programs focussed on fish endocrinology in Japan, and many notable research endeavors are not included. However, it is hoped that an impression of the depth of basic research interest in this area will be conveyed.

ENDOCRINE CONTROL OF MATURATION AND SPAWNING

The development of techniques to manipulate breeding in fish is essential to the growth of the fish culture industry. Many species do not breed naturally in captivity. In other species, induced spawning allows a greater control of fry production and also enables hybridization between related species. Spawning is often restricted to a short breeding season, and the ability to modify

the timing of reproductive events offers the possibility of more continuous production.

In teleosts, as in other vertebrates, the growth and maturation of the gonad are dependent on gonadotropic hormones secreted by the pituitary gland. The most common manipulative procedures include the use of fish pituitary extract, human chorionic gonadotropin, partially purified fish gonadotropins, hypothalamic gonadotropin-releasing hormone, and a range of pharmacological agents that act to enhance the secretion of endogenous gonadotropins. Currently favored strategies are gonadotropin-releasing-hormone analogs given singly or in combination with a dopamine antagonist to block the inhibitory action of hypothalamic dopamine on gonadotropin release (Figure 2).

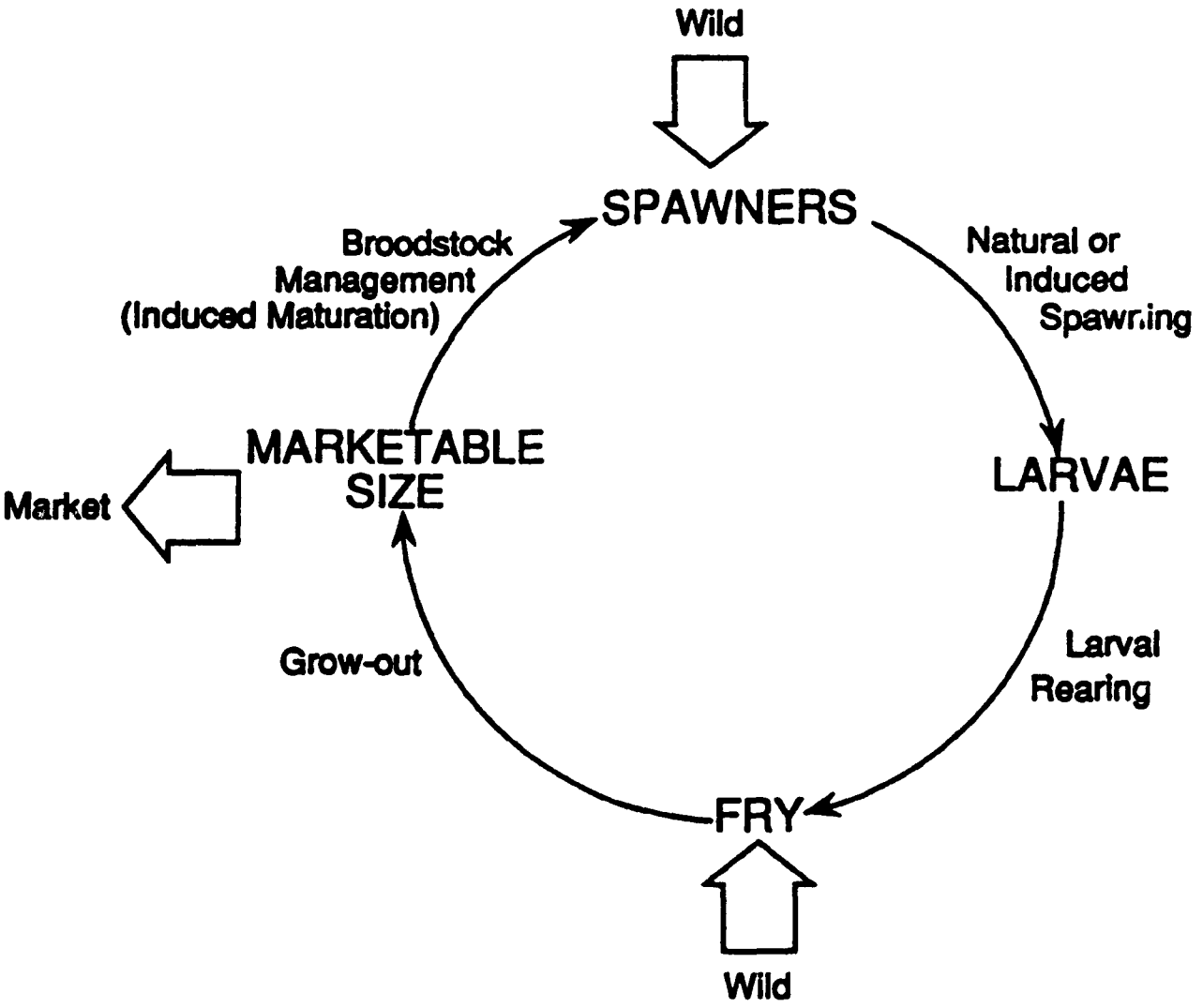

Figure 1. Life cycle of fish and major fish culture activities. Endocrine strategies are being developed to improve each phase of the cycle. Reprinted with permission from T.J. Lam, "Applications of endocrinology to fish culture," *Can. J. Fish. Aquat. Sci.* 39(1), 111-137 (1982).

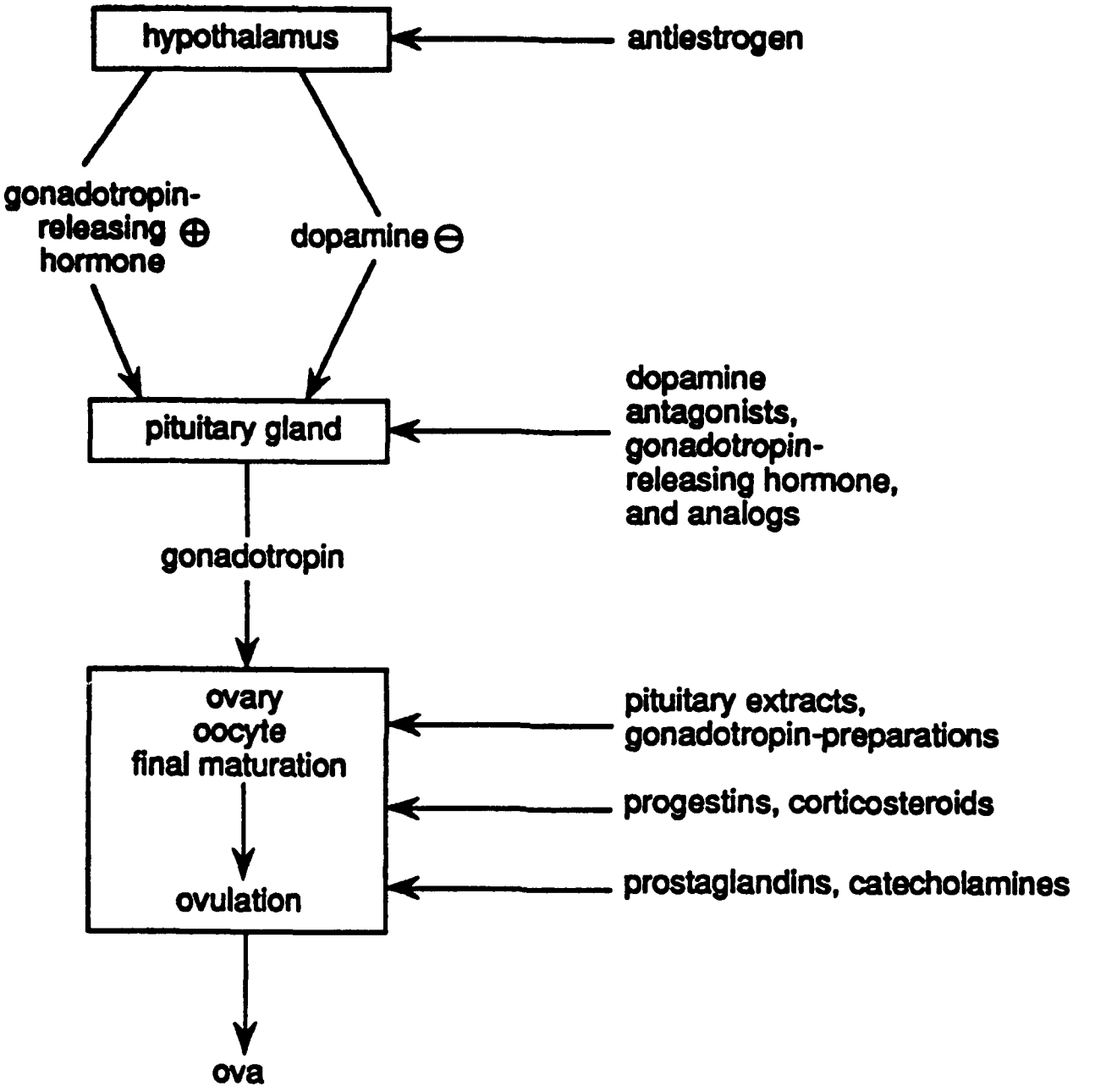

Figure 2. Hypothalamic-pituitary-ovarian axis in the teleost and the levels and types of intervention that can be utilized to induce final maturation and ovulation. These strategies were to a large extent adapted empirically from human clinical experience. From *McGraw-Hill Yearbook of Science & Technology 1990*, McGraw-Hill Publishing Co. Reproduced with permission of McGraw-Hill, Inc.

In recent years, interaction and collaboration between several groups of researchers in Japan have clarified the basic mechanisms through which gonadotropins influence gonadal maturation and spermatogenesis. The characterization of these mechanisms opens the door for the development of more direct approaches for manipulating reproduction in fish.

Workers at the Laboratory of Reproductive Biology, National Institute for Basic Biology (NIBB), under the direction of Yoshitaka Nagahama, have shown that growth and final maturation of the teleost oocyte are under separate hormonal control. As fish approach their spawning season, the oocytes undergo a remarkable increase in size as yolk proteins accumulate in the egg. The precursor protein of yolk, vitellogenin, is produced in the liver in response to stimulation by estradiol-17β produced by the developing follicles in response to gonadotropin stimulation. However, after the completion of their growth phase the eggs remain physiologically immature and cannot be fertilized. Using various salmonid species as their principal animal models, Nagahama's group has produced a unifying hypothesis for the endocrine control of oocyte maturation. According to this hypothesis the final maturation of the oocyte involves a cascade of three hormonal mediators: gonadotropin, maturation-inducing hormone, and maturation-promoting factor (Figure 3). Using an array of analytical techniques including reversed phase high performance liquid chromatography and mass spectrometry, the maturation-inducing hormone was purified from media in which fully grown but immature follicular oocytes had been cultured and was identified as the steroid 17α,20β-dihydroxy-4-pregnen-3-one (17α,20β-DP). Workers at NIBB, in collaboration with Dr. Kohei Yamauchi and coworkers at the Faculty of Fisheries at Hokkaido University and Dr. Kambegawa (Teikyo University), have shown that circulating levels of 17α,20β-DP are low during the vitellogenic phase of oocyte development but increase dramatically during maturation and ovulation. In addition, the capacity of isolated follicles to produce and secrete 17α,20β-DP in response to gonadotropin was shown to be acquired immediately before the natural maturation period. These temporal endocrine correlations together with the demonstration of a particular potency of 17α,20β-DP for oocyte maturation *in vitro* seem to establish this steroid as a physiological mediator of oocyte maturation in fish.

A recent series of experiments has revealed that 17α,20β-DP plays a parallel role in the male to that previously established in the female and appears to be involved in the final stages of sexual maturation. In male salmonids, 17α,20β-DP mediates the effects of gonadotropin and promotes spermiation and the acquisition of sperm motility. Thus 17α,20β-DP appears to be a singular example of a unisex hormone! A second remarkable characteristic of the maturation-inducing steroid, revealed in elegant microinjection experiments, is that it acts at the oocyte surface where it binds to specific receptors. This mode of action differs from other steroids studied which characteristically enter the cell and mediate their biological effects in the cytoplasm. The maturational effects of 17α,20β-DP have been shown to involve a cytoplasmic mediator termed "maturation-promoting factor" (MPF). MPF activity measured in terms of H1-histone kinase activity is highest during the first and second meiotic metaphase. MPF thus appears to be a final link in a chain that prepares the oocyte for fertilization. Research at NIBB is currently focussed on the molecular mechanisms of biosynthesis of 17α,20β-DP, the characterization of the cell surface receptors for this steroid, and the purification and characterization of fish MPF. In recognition of his central role in this fundamental research, Dr. Nagahama was awarded the Zoological Society of Japan Prize in 1989.

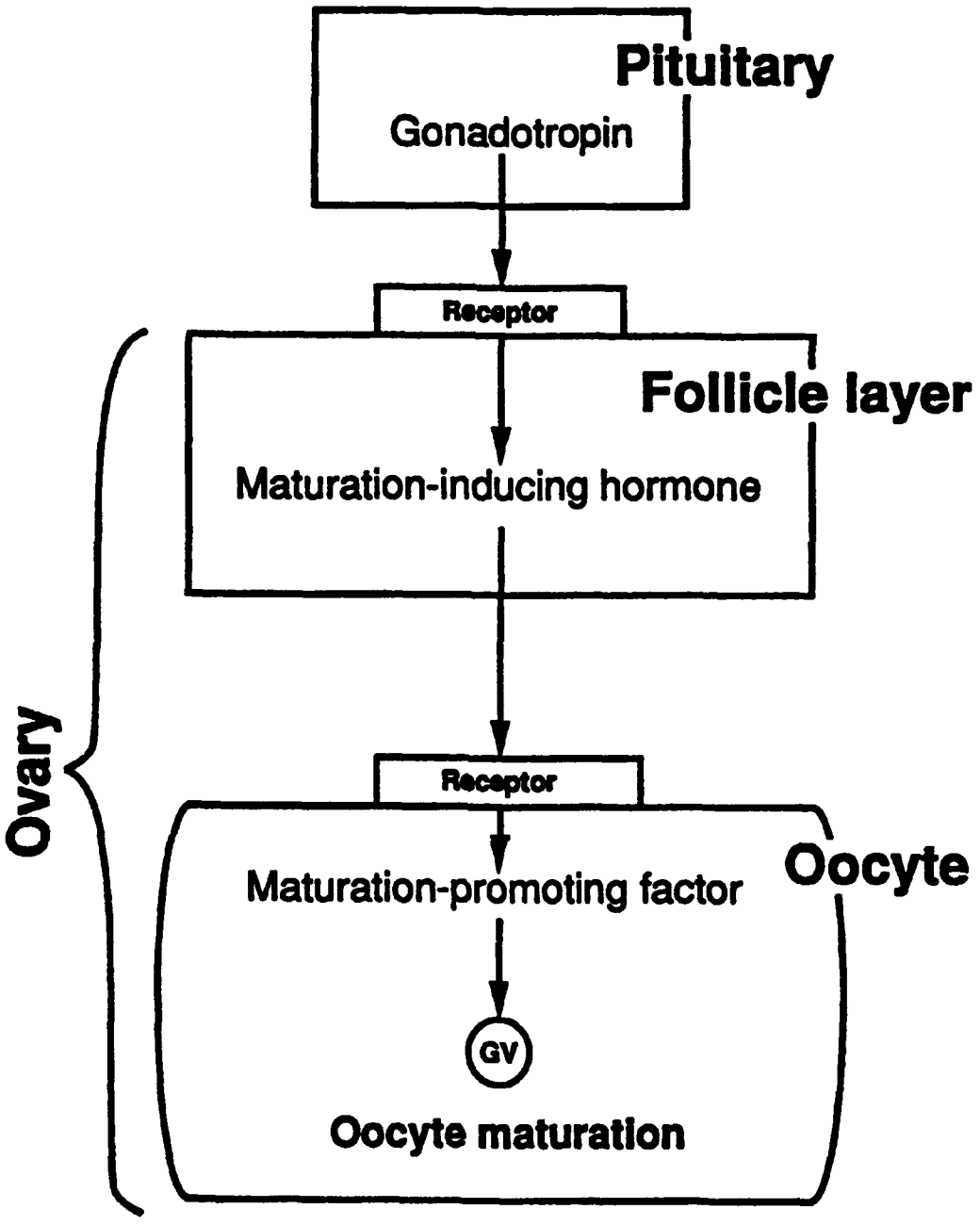

Figure 3. Hormonal regulation of oocyte maturation in lower vertebrates. From Y. Nagahama, "Gonadotropin action on gametogenesis and steroidogenesis in teleost gonads," *Zoological Science* 4, 209-222 (1987). Reproduced with permission of the Zoological Society of Japan.

LARVAL REARING

Problems of raising larvae through their transformation into juveniles impose a primary limitation on the culture of many marine species. This is particularly true of marine species that generally produce very small larvae with a low survival rate in culture systems. Larval rearing is at present the principal "bottle-neck" in fry (fingerling) production. The study of larval endocrinology is still in its infancy. The endocrine factors

regulating larval development and metamorphosis are poorly understood and there is scant information on the onset of endocrine competency of the endocrine system in fish.

Yasui Inui, Satoshi Miwa, and coresearchers at the National Research Institute of Aquaculture, Tamaki, Mie, in collaboration with Professor Tetsuya Hirano and his group at the Ocean Research Institute, University of Tokyo, have ongoing programs to study the involvement of thyroid hormones in the metamorphosis of the flounder--a very palatable marine flatfish with excellent potential for culture. Thyroid hormones are known to influence development in other vertebrates; a dramatic example of this is their role in the stimulation of the metamorphosis of amphibian larvae. However, until recently no comparable role for the thyroid had been found in fish. The collaborative study on the flounder has revealed that the pituitary-thyroid axis is functional very early in larval development. An immunocytochemical study of the pituitary cells producing thyroid-stimulating hormone (TSH) indicated increased reactivity during pre- and prometamorphosis and the onset of secretion during metamorphosis. Microinjections of TSH into the minute (8-12 mm) flounder larvae caused a surge of thyroxine in the tissues and accelerated the process of metamorphic climax. A comparable surge in thyroid hormone was detected by radioimmunoassay during normal development during the climax of metamorphosis. Addition of the two natural thyroid hormones thyroxine (T4) and triiodothyronine (T3) to the ambient seawater caused migration of the right eye to the left side, resorption of the dorsal fin rays, and other changes that normally occur during the flattening of the flounder during development. These hormone treatments produced miniatures of naturally metamorphosing benthic juvenile flounders. The comprehensive data emerging from these collaborative studies suggest that the role of the thyroid gland in fish extends beyond its known actions in regulating metabolic and behavioral changes and indicate that thyroid hormones are key regulators of fish metamorphosis. The potential application of thyroid hormone regimens to larval rearing will depend on the cost effectiveness of adding these hormones to the culture water or to artificial diets, the dose-response relationships for particular species, and the normalcy of the fry produced.

GROWTH AND SEX CONTROL

The time taken for most cultured fish to reach marketable size is long compared with most production cycles encountered in the food industry. Accordingly, food and equipment capitalization costs are relatively higher. Considerable emphasis is placed currently in aquaculture research on the development of biotechnologies to improve growth rates and food conversion efficiency.

The Japanese aquaculture community still favors conventional methods of genetic manipulation for improving stock characteristics of cultured fish. Marked improvements in growth rate and viability have been achieved through hybridization and induction of polyploidy. In addition, the production of monosex or sterile stocks can infer various advantages to cultured fish dependent on the species. In some species one sex grows faster than the other, and selective culture of the faster growing sex can significantly improve productivity. The culture of individual sexes or sterile fish also prevents breeding during the grow-out phase, and in some cases populations of such fish may grow faster because energy is diverted

from reproductive processes into somatic growth. In the case of salmon, where death follows spawning activity, sterilization can extend the lifespan by several years. Feminization and masculinization may be achieved by the application of estrogens and androgens, respectively, during sexual differentiation. Masculinized females may be used to produce an all-female stock indirectly, thereby avoiding the potential toxic effects of high doses of estrogens and their negative effects on growth. Masculinized females, while phenotypically male, retain the female genotype. Since the females are homozygous they produce spermatozoa that all carry the X-chromosome. Accordingly, when sperm from masculinized females are used to fertilize normal eggs, all female progeny will be produced. Single sex culture can also be achieved by manipulation of the genotype by the use of physical agents. For example, all-female progeny can be produced by fertilizing eggs with sperm that have been irradiated to destroy their chromosomal complement. The activated eggs are subsequently subjected to temperature or pressure shock treatment to prevent the separation of the second polar body or the first cell division. In this way the diploid condition is restored and the homozygous female condition is expressed. A similar methodological approach can be used to produce polyploid fish. To achieve the triploid condition, shock treatment is applied to prevent separation of the second polar body after eggs have been fertilized with a normal sperm. Tetraploidy may be induced by shock treatment of a normal zygote in order to prevent the first cleavage division and separation of the diploid set of chromosomes. Unlike triploids, tetraploid fish may become sexually mature, and the fusion of the diploid gametes from a tetraploid fish with normal haploid gametes is an alternative method of propagating triploidy. Triploid fish may be particularly vigorous and fast growing, and this is particularly true of triploid interspecific hybrids. This form of chromosome manipulation and selective breeding is a powerful tool for improving production in cultured species.

As in other vertebrates, growth in fish is controlled by a growth hormone (GH) produced by the pituitary gland. Studies on mammals have shown that the liver is a primary target for GH. GH binds to receptors on the liver cells (hepatocytes) and influences the pattern of intermediary metabolism in an anabolic direction. The role of GH in other vertebrates, particularly fish, has until recently been poorly understood. Growth hormones can now be produced by recombinant DNA technology in quantities which make their application in aquaculture a practical consideration. In addition, purification and determination of amino acid sequences have been achieved in Pacific salmon, rainbow trout, and the eel.

The Ocean Research Institute, University of Tokyo, under the direction of Professor Tetsuya Hirano, has a comprehensive program to examine the mechanism of action of growth hormone in fish and the physiological and environmental factors that influence its action. This program is supplying basic information that will help form a rational basis for the future application of growth hormone technology in fish aquaculture. Using GH isolated from the pituitaries of chum salmon and the eel, workers at the Ocean Research Institute have been able to characterize GH receptors in these species in an homologous hormone system. Preparations of liver membranes from trout and eel showed high specific binding for GH that increased linearly with the amount of tissue up to saturable levels. Furthermore, natural and recombinant GH

competitively displaced the labelled form of the endogenous hormone. The characteristics of this system fulfill the requirements of a radioreceptor assay for GH. Application of this type of assay would allow the development of growth hormone receptors to be monitored and a determination of whether the growth rate is a function of the number of receptors rather than a lack of systemic GH. Such information would allow a better prediction of the efficacy of potential GH regimens to improve growth rate. Interestingly, the group at the Ocean Research Institute found that ovine GH was more effective in displacing labelled eel GH than the homologous eel hormone. This is consistent with observations from other laboratories that have shown that mammalian growth hormones or their recombinant analogs can be more potent than the natural growth hormone in promoting growth in fish. The application of protein engineering to manipulate the amino acid sequence of recombinant forms of GH is likely to produce super-effective hormones with powerful growth promoting effects for use in fish culture. The assay developed at the Ocean Research Institute would provide an effective method for the initial screening of these products.

CONCLUDING COMMENTS

In surveying research on fish endocrinology in relation to aquaculture in Japan, one is impressed by the extensive interaction and collaboration which exist between individual institutions. A review of author locations on research publications reveals an intricate network of academic exchange. In addition, direct links often exist between research laboratories and the aquaculture and fishing industries. The emphasis on basic research to determine mechanisms of hormone action represents a long-term commitment to the improvement of our understanding of the way growth and reproductive function are controlled in fish. This approach is likely to pay dividends in the future in changing the endocrine regimens used in aquaculture from empirically based strategies to more specific manipulations.

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BIOMAGNETISM AND MAGNETOTACTIC BACTERIA

Aharon Gibor

Bacteria that move in response to magnetic fields are promising organisms for studies on biomagnetic effects. The "magnetotactic" bacteria are being investigated by several Japanese groups not only for their signal transduction properties but also for potential biotechnological applications. Biomagnetite particles, which are produced by the bacteria, are being studied as possible vehicles for localized drug applications. These very uniform micromagnetite particles are also used as carriers of enzymes for bioreactors and biosensor technologies.

The interactions of living organisms with the different prevailing natural forces are major fields of study in the biological sciences. Vision, photosynthesis, and geotropism are examples. A very interesting and still very mysterious interaction is the interaction of living organisms with magnetic fields.

The earliest interests in this field centered on the orientation and guidance of movements of migratory animals, mainly birds and fish, and the role of the magnetic field of the earth in this migration. The homing behavior of fish and birds is a fascinating phenomenon that attracted much attention from biologists. For a review see Reference 1. To explain the ability of organisms to sense the magnetic field of the earth, two basic mechanisms were proposed:

(1) Detection of an electric field, arising by the Faraday effect, from the motion of the electrically conducting body of the organism through the magnetic field.

(2) Response of the magnetic materials that are embedded within the body of the organism to the magnetic field of the environment. This can cause physical dislocations of the magnetic material that are sensed by the organism.

The recent discovery of the presence of "magnetotactic" microorganisms in aquatic muds (Ref 2) and soils (Ref 3) provided new impetus to studies on biomagnetism. These organisms respond to magnetic fields by active movement and aggregation at one or the other pole of an imposed magnetic field and are referred to as magnetotactic. By electron microscopic studies it was found that the magnetotactic organisms contain within their cells magnetite particles with dimensions a minute fraction of micron that are often arranged in strings along the longitudinal axis of the cells.

The discovery that such magnetotactic microbes are prevalent in soils and aquatic environments attracted the attention of geologists and geophysicists, who were studying the phenomenon of remanent magnetization, which is seen in many sedimented mineral deposits. The origin of mineral deposits is of prime interest to geologists. The biosphere plays a role in the deposition

of different minerals and biomineralization is an important area of geochemistry and geophysics research. The discovery of the prevalence of magnetotactic microorganisms led to investigations of their role in the deposition of magnetite particles in nature. Such micromagnetite particles could explain the origin of remanent magnetization in mineral deposits. The abundance of these magnetotactic organisms strengthens this idea. While the presence of magnetotactic bacteria in anaerobic saline and freshwater sediments has been known for some time (Ref 2), such bacteria were also found recently in typical meadow soil (Ref 3). It is thus quite reasonable to assume that the fossils of magnetotactic bacteria are responsible for the observed magnetic properties of mineral deposits.

Magnetotactic bacteria also are finding applications in several other areas of research. In recent years, especially in Japan, innovative studies were initiated on the possible biotechnological exploitation of these magnetotactic bacteria for the synthesis of micromagnetic particles uniform in size and shape. Such particles could be useful for many applications in biotechnology.

One very clever application of magnetotactic bacteria for astrophysical and geophysical studies was published last year by M. Funaki, H. Sakai, and T. Matsunaga (Ref 4). This is a cooperative study by a geophysicist from the National Institute of Polar Research (Funaki), a geologist from the Department of Earth Science of Toyama University (Sakai), and a microbiologist from Tokyo University of Agriculture and Technology (Matsunaga). This innovative study is analogous to the classic work of Engelmann, in the early part of the century, in which he used the motility of aerobic bacteria as an indicator of the presence or generation of oxygen. He was thus able to demonstrate an action spectrum for oxygen production in photosynthesis by projecting the light spectrum onto a chain of algal cells on a microscope slide in the presence of such bacteria. The localized motility of the bacteria was an indicator of oxygen production.

In the present study the presence of magnetic grains in a small fragment of a meteorite, a fraction of a millimeter in size, was plotted by following the direction of movement and accumulation of the magnetotactic bacteria. By the use of south-seeking and north-seeking strains of bacteria, the polarity of the micrograins could also be determined. In fact, the bacteria were used as ultramicro magnetometers.

Natural remanent magnetization (NRM) was studied in the past by the orientation of suspensions of artificial magnetite colloidal particles; however, the magnetic polarity cannot be determined by the use of this method. The charting of the migration pathways of the specific bacteria strains and their accumulation enables the determination of magnetic polarity and the direction of the lines of magnetic force radiating from the mineral grains (Ref 4, Figures 1 and 2).

Prof. Matsunaga of the Tokyo University of Agriculture and Technology is studying several possible applications of magnetotactic bacteria themselves or of the magnetite particles that can be isolated from them. One of the problems for possible technological use of these organisms is the difficulty of mass culturing of pure cultures of these bacteria. Active research is being pursued both in the United States and in Japan for developing the appropriate culture media and culture conditions for mass production of these organisms.

Matsunaga and coworkers consider the magnetite particles as possible vehicles for site-directed drug applications. As a model system they studied the particles as carriers of enzymes (Ref 5). Enzymes were bound to magnetic particles that were isolated from

bacteria. The bacteria themselves were collected from sewage sludge by a harvesting instrument that attracted these bacteria to a magnet. The bacteria that accumulated near the magnetic poles were harvested with a pipet. Thus, they were studying a mixed population probably made up of numerous different species. By microscopic observations they described the bacteria as mainly cocci and rod type cells. The cells were washed in water and then digested with 5M NaOH for 12 hours. The remaining particles were washed in water and collected either by centrifugation or by attraction to magnets. Samarium-cobalt magnets were used in these studies. About 20 μg of magnetic particles were isolated from 1 mg dry weight of bacteria. The particles were almost uniform in size and cuboidal in shape, with an average length of 100 nm and an average width of 50 nm.

A comparative study on the relative effectiveness of the biomagnetite particles versus artificial fine-powdered particles was performed. The artificial magnetite particles and Zn-ferrite particles are irregular in size and shape and they tend to form large aggregates, while the bacterial particles do not. It is not obvious why the bacterial particles do not form aggregates. It is likely that some alkali-resistant organic residues remain on their surfaces. Some microscope pictures indicate that a fuzzy layer, perhaps made up of lipids, is coating the biologically produced particles.

The particles were siliconized then immersed in solutions of the enzymes glucose oxidase or uricase. The enzyme molecules were bound to the particles by subsequent treatment with glutaraldehyde. The results of these studies are presented in Table 1. The biologically produced particles were found to bind much more enzymes and had a higher enzymatic activity per milligram powder than the artificial powders. The particles retained their enzymatic activity on repeated use. For glucose oxidase the original activity was retained for five reuses. It seems, however, from the data presented that the specific activity, i.e., activity per milligram bound enzyme, was lower for the bacterial particles.

Figure 3. Trails (perforated line) and swarming regions (dotted area) of the north-seeking bacteria of sample A (reprinted with permission from Terra Scientific Publishing Co.).

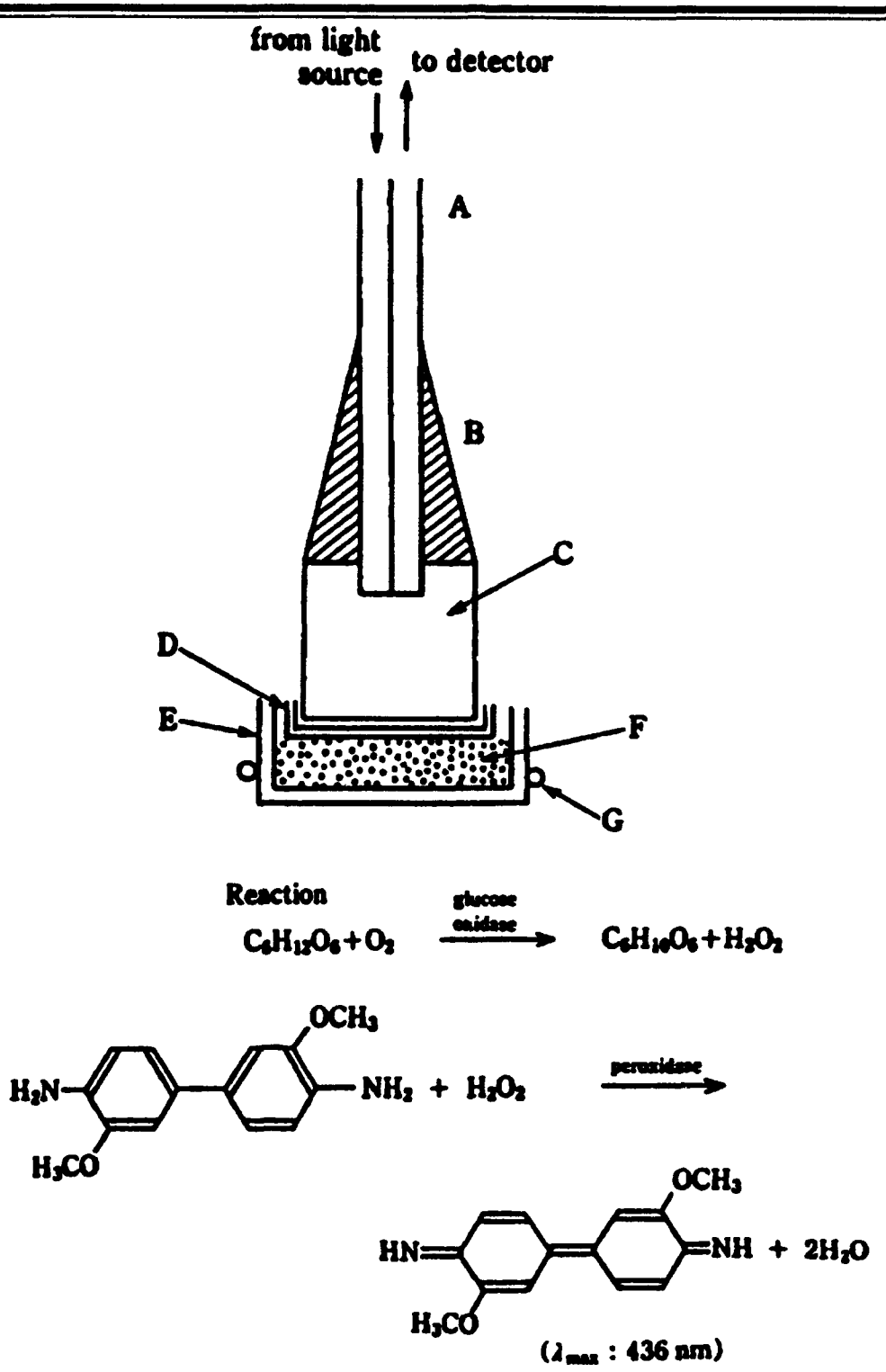

Figure 2. Schematic diagram of optic fiber probe based on reflected light intensity: A, optical fiber; B, epoxy resin; C, color-producing phase; D, membrane filter; E, cellulose membrane; F, enzyme reaction phase (containing glucose oxidase immobilized on bacterial magnetites); G, O-ring. Reprinted with permission from *Chemical Sensor Technology* (ed. by T. Seiyama), vol 2, p. 261, Kodansha, Tokyo, 1989.

Table 1. Immobilization of Glucose Oxidase and Uricase on Separated Biogenic Magnetic Particles, Magnetite and Zn-Ferrite (adapted, with permission, from Ref 5)

Type of Particles	Enzyme	Amount of Immobilized Enzyme (μg/mg)	Enzyme Activity (U/mg)
Separated magnetic	Glucose oxidase	200	59
	Uricase	196	0.59
Magnetite	Glucose oxidase	2.5	1.8
	Uricase	7.6	0.02
Zn-ferrite	Glucose oxidase	1.8	1.5
	Uricase	5.9	0.015

In another application (Ref 6), particles carrying glucose oxidase and peroxidase were used for the assembly of glucose sensors (Figure 2). For other possible applications, particles were coated with antibodies and used to detect the presence of antigens in biological fluids. The presence of the latter molecules caused the aggregation of the coated particles. The degree of aggregation could be evaluated by direct microscopic observations or, when fluorochrome-conjugated antibodies were used, by the decrease in the measured fluorescence of the solution which resulted from the aggregation of the fluorescing particles. Exposure of the reaction mixture to magnetic fields was found to accelerate the rate of the aggregation.

The possible application of magnetic particles in medicine for the guidance of immunocompetent cells in the body was also studied. It was possible to introduce the magnetotactic particles into animal cells either by cell fusion (Ref 7) or by phagocytosis of the bacterial cells by granulocytes and monocytes (Ref 8). The animal cells with the included magnetoparticles retained their viability and could be made to migrate in a magnetic field. It is thus suggested that immunocompetent cells could be magnetically guided to attack cancer cells. Leucocytes containing magnetic particles might also be used to locate and visualize tumors by magnetic resonance imaging after they become associated with the tumors.

Matsunaga's laboratory is now studying the use of these particles, coated with specific genetic probes, for "fishing-out" specific genes or gene products from solutions or from live cells. The latter task they hope to accomplish by shooting the particles into live cells and subsequently pulling them out with a magnet.

Another laboratory that is actively engaged in research on magnetotactic bacteria is that of Prof. Koki Horikoshi of the RIKEN Institute. Because of the difficulties in culturing the magnetotactic bacteria, they focused their studies on the possibility of synthesizing these magnetite microparticles in vitro. Some controversy arose concerning the need for specific genetic factors for the production of the micromagnetite particles. Because the shape and size of the particles are unique for different bacterial species, it suggests that a genetic factor might be involved in directing their biosynthesis.

In two recent publications (Ref 9 and 10), Horikoshi's group concluded that regulation of the pH and the redox potential at specific sites within the cells of the magnetite-producing organisms is sufficient to cause the synthesis of these particles. No specific enzymes are required; rather the chemical environment and the products of common biochemical reactions are sufficient to promote the crystallization of magnetite particles.

They demonstrated that the enzyme urease, when added to a solution that contains urea, ferrous chloride, and potassium nitrate and maintained sealed under nitrogen, will cause an increase in the pH (due to ammonia production from the urea). This shift in pH first caused the formation of ferrous-hydroxide gel. Later the greenish gel darkened and black magnetite crystalline particles precipitated. Oxidation was probably caused by the nitrate in the presence of trace amounts of oxygen, which catalyzes the oxidation. The same reaction if occurring under aerobic conditions does not result in the formation of magnetosensitive iron oxides. The magnetite particles that were formed under these conditions were made up of particles in a range of sizes, averaging 200 nm in diameter and more or less spherical in shape. The particles were identified as magnetites by their Mossbauer spectrum and x-ray diffraction patterns. When magnetite particles are formed within living bacterial cells, they are usually between 40 and 120 nm in size and have shapes that are characteristic for the bacterial species. Thus, a genetic input on the pattern of growth of the crystals is indicated.

Further evidence that the particles synthesized by different bacterial species differ in their properties was presented by Moskowitz et al. (Ref 11), who demonstrated different responses of such particles to temperature variations.

Frankel and Blakemore (Ref 12) also claim that the protein makeup of the magnetosome membranes differs between different bacterial species; such proteins might play specific roles in iron accumulation and deposition. They also claim that bacterial mutants which lost their response to magnetic fields also lost their magnetosome membranes. Normal bacteria when cultured in the absence of iron did not develop magnetite particles, lost their magnetotactic abilities, but retained their magnetosome membrane vesicles. The latter observation suggests that the deposition of unique magnetite particles is genetically controlled and perhaps specific proteins could be isolated that will promote the crystallization of magnetite particles of unique shape and properties. The size and shape of the biologically produced particles might be constrained by the "magnetosome" envelope in which they are growing. It was also suggested that nitrate reduction by the appropriate enzymes, i.e. nitrate reductase, is necessary for magnetite biosynthesis. It was noted that magnetotactic bacteria when grown anaerobically on ammonium rather than nitrate did not produce magnetite.

Very slight changes in the reaction conditions, especially the trace amounts of oxygen, were critical for the formation of the magnetite microcrystals. Thus the formation of magnetite within the living cell is greatly dependent on the overall biochemical environment in which the organism finds itself. For example, the concentration of nutrients, especially the availability of iron, and the concentration and rate of supply of oxygen are critical factors for the biosynthesis of magnetite.

More recent studies in Matsunaga's laboratory also include the refinements of the microenvironment for the in vitro synthesis of the magnetite particles. One of their most recent innovations is the confinement of microdroplets of the reaction mixture in lipid membranes, so-called liposomes. They are investigating the influence of the composition of thelipid portion of the liposome membrane on the properties of the magnetite particles that are being generated.

In conclusion, it is becoming apparent that the fine magnetite particles that were discovered within the magnetotactic bacteria are sensors that cause the organisms to

respond to magnetic fields. They are also very promising as possible vehicles for manipulating the localization of macromolecules in biotechnological processes.

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BIO JAPAN '90-OSAKA

Aharon Gibor

The main theme of this conference was the contribution of biotechnology to the creation and conservation of our green planet. Special emphasis was placed on developments in the manipulation of plants and the implications from these developments on the global ecological problems and on the manipulation of protein molecules and understanding the biological activities of these macromolecules.

INTRODUCTION

This conference was organized in conjunction with the International Garden and Greenery Exposition, which was held in Osaka. The main theme of the conference was the contribution of biotechnology to the creation and conservation of our green planet. Among the sponsors of the conference was the Japan Bioindustry Association, the leading organization of the biotechnology industries.

About 400 people attended the Osaka meeting. They were mostly from Japanese companies and institutions. I estimate that the number of foreigners was no more than 10% of the total. All the presentations had simultaneous translation.

An elaborate exhibition of scientific instruments and equipment was held concurrently. The exhibitors were mainly Japanese companies. The exhibitions included a large number of controlled culturing arrangements with elaborate "bioreactors" for cultivation of cell suspensions of plants or animals. Of special interest were the micromanipulation and microinjection devices advertised for genetic engineering manipulations such as injection of eggs.

DISCUSSION OF THE SCIENTIFIC PROGRAM

Two concurrent sets of sessions were held; one set was directed primarily to plant biotechnology while the other dealt with protein engineering as well as medical and pharmacological technologies. I attended mostly the plant biotechnology sessions but went also to several interesting lectures on protein engineering.

The papers presented on plant biotechnology included general introductions to the manipulations of plants, their tissues, their isolated cells, and their genes and gene expression. The basic aspects of the science were introduced by papers such as "Progress in Plant Engineering," by Marc Van Montagu (Belgium); "Green Life, Aesthetics, and Necessity," by J.B.E. Simmons (curator of Royal Botanic Gardens, Kew, U.K.); and "The Application of Micropropagation in Improving the Living Environment and Greening the Globe," by I.Y.E. Chu (Ventura, CA). The role of plants in the global environment was discussed by D.O. Hall (London, U.K.). Prof. Nam-Hai Chua of Rockefeller University spoke on the control of cell specific gene expression in the development of plant tissues.

In general, most of the papers that dealt with basic scientific developments were presented by foreign scientists, while most of the more direct applications papers were from Japanese laboratories.

Prof. Hideaki Yamada of Kyoto University described his research on halogenating enzymes from brown seaweeds. Specific non-heme iron containing enzymes and others that contain vanadium and are specific for bromination or iodination were isolated and studied. The essential role of vanadium was demonstrated, but the mechanism of the reactions is still being investigated. These enzymes are being studied for application to specific halogenating reactions in industrial organic synthesis. (These studies are in agreement with those of Prof. Alison Butler of the University of California at Santa Barbara on the haloperoxidases of brown seaweeds.)

Dr. Y. Ohta reported on the cultivation of liverwort cells and their secondary metabolites. Several interesting aromatic substances as well as substances with other biological activities such as plant growth regulations were found in different liverworts. The possibility of stimulating the production of these secondary metabolites by cells cultured under controlled conditions is being investigated. Cell suspensions of liverworts are green and can be grown photoautotrophically for their secondary metabolites in illuminated bioreactors.

Further studies on secondary metabolites, especially the biosynthesis of tobacco alkaloids, were reported by Professor E. Leete of the University of Minnesota. The intricate metabolic pathways were studied by feeding labeled putative precursors to different tissues of the plants and isolating and characterizing the intermediates. This was followed by attempts to isolate and characterize the responsible enzymes.

The production of anthocyanin pigments by different cell lines of *Euphorbia* is being studied by Y. Yamamoto of the Nippon Paint Co. By selecting highly pigmented callus like cell colonies and controlling growth conditions, they were successful in increasing 26-fold the level of pigments in the cells. They also demonstrated that the extracted pigment can be used for dying silk cloth.

M. Kawamura and coworkers of the Kyowa Hakko Kogyo Co. are studying the production of an insecticide using the tissues of the lopseed plant *Phryma leptostachya.* These insecticides are lignans named Haedoxan-A, which are similar to others that are widely distributed in higher plants. The potential applications of these insecticidal substances are being investigated.

An interesting report by Prof. Tsutomu Furuya of Kitasato University described the successful cultivation of tissues and cells of several plants for the production of pharmaceutically important substances. Tissues of *Panax*-ginseng were used for the production of ginseng saponins. Large scale, 20-ton tanks were used to produce ginseng root cultures. Production rates of up to 700 mg dry weight of roots per liter per day were achieved. The saponin contents of these roots was close to that of naturally cultivated ginseng roots. Eucalyptus cell suspensions were used for biochemical transformations of menthol and glycyrrhetinic acid to various derivatives.

Prof. Tage Eriksson, from Uppsala, Sweden, described his accomplishments in propagating spruce trees by microculture techniques. Techniques for the cultivation of tissues and induction of embryos for production of plantlets were developed. Protoplast production and cultivation techniques were also developed. The latter techniques are especially useful for genetic engineering of these forest trees.

The role of forestation and reforestation for controlling the rise in atmospheric CO_2 was discussed by Eriksson as well as by D.O. Hall and J.B.E. Simmons.

It is apparent that great strides are being made in the manipulation of many economically important plants. Not only are new genetic factors being introduced into cultivated plants, but specific plant tissues and cells are being grown in industrial bioreactors for the production of valuable products.

In other aspects of biotechnology, several interesting papers were presented on protein engineering in general and the creation of new enzymes. I learned a lot from the paper given by Kim D. Janda of the Scripps Clinic at San Diego. He described the strategies used for the production of catalytically active monoclonal antibodies. An antigen is designed so that it resembles the intermediate, transition state molecule in an enzymatic reaction. The binding site of the antibody will bind, hopefully, the transition stage and thus stabilize it long enough to facilitate the subsequent reactions that are associated with the molecular environment of the binding site.

Prof. Takahisa Ohta of Tokyo University reported on studies in which they manipulated specific sites in the enzyme lactic dehydrogenase in order to understand the regulation of enzyme activity by the so-called allosteric effects. Fructose 1,6-bisphosphate (FBP) has such an allosteric effect on some lactic dehydrogenases. They were able to demonstrate the role of a specific arginine residue, Arg-173, in the response of the enzyme to FBP. An enzyme with a modified Arg-173 was independent of the FBP allosteric effect. By such chemical modifications and by site specific mutations they are studying the role of several amino acid residues around the active sites for further understanding of the catalytic action. The conformational changes of the enzyme subunits and of the aggregated units as a consequence of binding of the substrates and of the allosteric inducers are being studied.

A very interesting paper was presented by Prof. Tairo Oshima on proteins, especially enzyme stabilization, in thermophilic bacteria. Apparently there are no generalizations that can be made on the modifications in a protein makeup which result in its thermal stabilization. In many cases an increase in the proline residues and a decrease in the number of cysteine, aspartic, and ornithine residues were found to be associated with the stabilization of the enzymes. They chose to investigate the enzyme D-3-isopropylmalate dehydrogenase. The gene coding for this enzyme is called leuB in bacteria and leu2 in eukaryotes. The gene was cloned from extreme thermophils, moderate thermophils, and mesophilic bacteria. The genes were sequenced, and these genes and their product peptides are now being studied.

The highly thermophilic enzyme is a dimer of identical subunits. Mg or Mn are required for activity; no cysteine is present in the peptide and high concentrations of K ions are required for enzymatic activation. The three-dimensional structure of these enzymes is being studied in cooperation with Prof. Katsube of the Osaka Protein Institute.

In another approach to understanding the significance of the different sectors of the protein molecule in making the final molecule heat stable, they are producing chimeric enzymes by connecting segments of the genes from the extremely temperature stable genes to those of the mesophilic genes. The chimeric genes are expressed in *E. coli* and the enzymes are isolated, crystallized, and their shape and thermal stability determined. By this technique they hope to determine what amino acid sequences are responsible for the added thermal stability of the enzyme.

Another approach to the study of protein stabilization was described by I. Urabe et al. from Osaka University. They studied the thermal stability, resistance to alkaline treatment, and pH stability of the enzyme glucose dehydrogenase. The enzyme from *Bacillus megaterium* is a tetramer of identical subunits. It is inactivated in alkaline solution due to the disassociation of the tetramer to the inactive protomers. The gene coding for this enzyme was isolated and randomly mutagenized by chemical treatments in vitro. The treated genes were reintroduced into bacteria and mutants with increased heat stability and they were subsequently isolated and studied. The specific amino acid substitutions that conferred increased thermal stability were determined. Some of these substitutions also conferred alkaline resistance to theresulting enzymes, indicating that the increased stability can be attributed to stabilization of the oligomeric structuring of the enzyme. Substitution of the amino acid Glu at position 96 by either glycine or alanine or substituting cysteine for tyrosine at position 253 stabilized the tetramer at pH 9 and also at reduced salt solutions. They concluded that these two positions are probably on the surface of the protomer and when they become negatively charged at alkaline pH they contribute to the repulsion between the protomers and cause breakdown of the oligomers. This study is a good example of information on the quaternary structure of proteins that can be obtained without crystallographic studies.

CONCLUDING REMARKS

In summary, this meeting presented interesting advances in several areas of biotechnology. There was a special emphasis on developments in the manipulation of plants and the implications from these developments on the global ecological problems. A second subject area emphasized was the progress on manipulating protein molecules and understanding the biological activities of these macromolecules. The implications of these technologies to advances in medicine were also considered.

INTERNATIONAL BIOSENSORS CONFERENCE AND WORK IN THE ASIA-PACIFIC REGION

Malcolm Haskard

The area of biosensors is a new and exciting field that has not only opened new areas but promises considerably improved sensor performance in existing areas. This paper reports on the first International Biosensors Conference, which focused on work which is being undertaken by countries in the Asia-Pacific region.

INTRODUCTION

Biotechnology is a field of growing interest world-wide. It includes the area of biosensors, devices that in many instances offer improved selectivity and increased sensitivity over conventional chemical sensors. In the broadest sense a biosensor is any sensor that measures the concentration of a biological substance. However, the more usual definition is an analytical device that combines a transducer with a biologically active substance.* The transducer is normally electronic with the coupling to the biological substance either direct (e.g., through an electrode, ion selective field effect transistor (ISFET), or thermistor) or indirect (e.g., optical fiber).

The International Biosensors Conference held in Singapore from 2 to 4 May 1990 was the first world congress on the topic. The organizers plan to hold such conferences every 2 years. At this conference there were 19 invited and plenary speakers, 87 contributed papers, and 80 poster papers having overall about a 50:50 mix of academia and industry. Some 260 people attended from 32 countries.

Table 1 shows the number of papers from each country. Where there are joint authors from different countries the paper is shown under all countries which were involved.

Table 1. Papers Presented on a Country Basis

Country	Invited	Oral	Poster	Total
Australia	-	-	2	2
Austria	-	2	2	4
Belgium	-	1	1	2
Canada	-	1	-	1
China	2	5	20	27
Finland	-	1	-	1
France	-	3	4	7
W. Germany	1	11	10	22
E. Germany	1	1	-	2
Hong Kong	-	-	1	1
India	-	-	1	1
Italy	-	2	-	2
Japan	3	20	18	41
Netherlands	1	3	4	8
Philippines	-	-	1	1
Singapore	-	1	-	1
Spain	-	-	1	1
Sweden	1	3	2	6
Switzerland	1	5	2	8
Taiwan	-	-	1	1
U.K.	2	16	6	24
U.S.A.	5	10	3	18
U.S.S.R.	1	3	5	9

*Madou, M.J., and S.R. Morrison (1989), *Chemical Sensing with Solid State Devices* (Academic Press, Boston).

The program for each day was such that the morning was devoted to plenary and invited speakers, the afternoon to three streams of oral papers, and the evening to poster papers. (It was disappointing that about half the poster papers were not presented.) Sessions were divided into five groups: glucose biosensors, affinity sensors, microbiosensors, flow injection analysis (FIA), and general biosensors.

INVITED SPEAKERS

Six papers on different aspects were presented each morning. The first morning papers focused on affinity sensors, the second on glucose biosensors, and the third on microbiosensors, flow injection analysis, and general aspects. The papers on the first morning predominantly examined different transducer approaches to produce immunosensors, namely, optical, piezoelectric, electrochemical, thermal, and impedance measurements. The invited papers dealing with the measurement of glucose looked at past and present approaches including commercial instruments. The development was broken down into three generations characterized by the interrelation between the functional steps—molecular analyte recognition, physiochemical (product) selection, and signal processing. The first generation employed amperometric glucose oxidase electrodes, that is, the anodic detection of peroxide. There were two problems: the interference by electrochemically oxidizable sample constituents such as paracetamol and the restriction of the measuring range by the need of a cosubstrate supply. The second generation employed both mediator-modified enzyme reactions, such as in the ferrocene-based glucosesensor, and recycling resulting in increased sensitivity and an extended linear range. In the third generation multiple ISFET transducers allowed the simultaneous use of different enzymes, e.g., the detection of glucose and urea or glucose and trioleate. Further, because the sensor is so compact, allowing microsamples to be analyzed, noninvasive methods of glucose measurement for diabetics now appear possible.

On the final morning invited speakers concentrated on two main aspects, namely, microelectrodes and flow injection analysis. Under the first topic a number of electrodes and methods were discussed based on the use of microelectronics and other high technologies. Included were carbon fiber (tip diameter of 5 microns) and glass (diameter of 0.1 to 0.5 micron) microelectrodes, printer ink jet methods to manufacture small enzyme membranes for ISFETs, and membranes for optodes (chemical sensing using optical fiber transduction) that allow responses to several different types of ions. Flow injection analysis methods were shown to be an excellent tool for rapid and highly selected automated analysis. Application examples given were online bioprocess control and food and water analysis.

ORAL AND POSTER PAPERS

Oral and poster papers covered an extremely wide range of topics. At one end were the experimenters trying out radically different materials and methods and at the other the development of new ideas and understanding using analytical methods. In-between were those who have developed new products by extending existing technology. The weight of papers was heavily in favor of the biologists and chemists with a considerably lesser number on the microelectronic and engineering side. It appears that although microelectronic sensors have been around for many years, the technology is only now being applied in earnest to biosensors. Perhaps one reason for this is the need for team work, teams involving a whole range of disciplines, with microelectronic specialists being another group which has to be added to an already large team.

There were eight countries from the Asia-Pacific region presenting papers: Australia, China, Hong Kong, India, Japan, the Philippines, Singapore, and Taiwan, with Japan and China dominating the scene. The significant papers and work will now be considered in more detail.

PAPERS FROM THE ASIA-PACIFIC REGION

Australia

Although only two papers were presented, there are several groups in Australia active in the biosensor area. There is a recently formed network of people interested in sensors (see Table 2). In summary, the major research groups are within the Commonwealth Scientific and Industrial Research Organization and educational establishments. Both papers were from the latter category. The first paper by Dr. Alexander and two colleagues from the Department of Analytical Chemistry, University of New South Wales, describes work using multiple sensors series connected in FIA to increase sensitivity. Dr. Wlodarski at the Royal Melbourne Institute of Technology was joint author of the second paper and is involved in sensor research with a number of overseas and interstate universities. This includes the Microelectronics Centre at the South Australian Institute of Technology, which has for many years been active in the sensor field (both physical and chemical sensors) and has recently become involved in cooperative work on biosensors. The work reported in this paper, and undertaken with two institutions in Shanghai, concerns the detection of organophosphorus pesticides in water using an immobilized butyryl cholinesterase membrane and a pH ISFET sensor. Water purity is a growing world problem and is particularly important to Australia, the driest continent in the world. Five papers at this conference were concerned with monitoring water purity.

Table 2. Australian Sensor Network, Summary of Members

Organization Type	Scientists	Engineers	Interest in Biosensors
Australia			
Government	5	1	4
Industry	1	5	4
Education	4	2	5
New Zealand			
Government	1	1	-

China

It is surprising that China presented the second to the highest number of papers, surpassed only by Japan. While the location of the conference may have assisted, it is still evident that China is placing considerable emphasis on biosensors. Some 11 academic institutions, 9 Government, and 1 commercial organization reported on their work at the conference. Table 3 lists these establishments.

Work in China covers a wide range of topics and includes:

(1) The measurement of body materials such as hemoglobin, myoglobin, cytochromes, histamine, serotonin, uric acid, and glucose.

(2) Neural research.

(3) Conventional and novel sensor development (such as using animal tissue, a slice of kidney cortex).

Table 3. Chinese Establishments Involved in Biosensor Research

Type	Name
Academic	Changchun Inst of Applied Chemistry East China Univ of Chemical Tech (Shanghai) Fudan Univ (Dept of Biochem) Guangdong Medical & Pharmaceutical College (Dept of Pharm Anal) Hangzhou Inst of Electronic Engineering Harbin Inst of Tech (Dept of Environmental Chem Eng; Dept Semiconductor Phys & Dev) South China Univ of Tech (Lab of Biosensors) Southeast Univ (Dept of Biomedical Engineering; Microelectronics Center) Tongji Medical Univ (Environmental Med Inst) Univ of Sci & Tech (Dept of Applied Chem) Zhejiang Univ (Lab Cell Physiology; Dept Scientific Instruments)
Government	Inst of Microbiology[a] Inst of Semiconductors[a] Research Center for Eco-Environmental Sciences[a] Shanghai Academy of Agricultural Sciences Shanghai Center of Biotechnology Shanghai Inst of Biochemistry Shanghai Inst of Metallurgy Wuhan Inst of Virology[a] Wuhan Instrumental Inst
Commercial	Wuhan Modern High Tech Co.

[a]Chinese Academy of Science.

(4) Measurement of commercial materials such as methanol, penicillin, and glucosinolate in rape seed.

(5) Water treatment, biochemical oxygen demand (BOD), pesticide residues.

(6) Measurement of "Qi" energy.

Hong Kong

One paper was presented on work being undertaken jointly by the Department of Applied Biology and Chemical Technology at Hong Kong Polytechnic and the University of Michigan in the United States. At present it concerns testing for the drugs ampicillin and capsulae cefalexini in *E. coli* cells using a matrix of biosensors interfaced into a personal computer. Software has been developed for data acquisition, database management, and data analysis.

India

An interesting paper was proposed by Dr. Singh of the National Physical Laboratory

at New Delhi on piezoelectric bone biosensors. Unfortunately, the paper was not presented.

Japan

Some 41 papers were presented, the most from any country. Table 4 lists the 25 establishments that submitted papers, the majority being industrial organizations. Two academic institutions have special departments concerned with biotechnology/bioengineering.

While the range of topics was diverse, there was a bias towards industrial applications and the use of microelectronic methods. Novel topics included:

(1) Medical applications—allergy sensing, detection of fatigue substances in sweat, disease-related constituents in urine, sodium and potassium ion measurement in serum, measurement of blood coagulation factors, glucose sensing in tissues, sensing of anesthetics.

Table 4. Japanese Establishments Involved in Biosensor Research

Type	Name
Academic	Kanagawa Inst of Tech (Dept of Chem Tech) Kumamoto Univ (Faculty of Engineering; Medical School) Kyoto Univ (Dept of Agricultural Chem; Dept of Chem & Materials) Kyushu Inst of Tech (Dept of Applied Chem) Saitama Univ (Faculty of Engineering) Soka Univ (Inst of Life Science) Tokai Univ (Dept of Clinical Pathology) Tokyo Inst of Tech (Dept of Bioengineering; Dept of Polymer Chem) Tokyo Univ of Agricultural Tech (Dept Biotech) Univ of Tokyo (Research Center Advanced Science & Tech)
Government	Government Industrial Research Inst National Inst of Health (Dept of Blood Products) Research Inst for Polymers & Textiles
Commercial	DKK Corp. Fujitsu Laboratories Ltd. Komatsu Ltd. Mitsubishi Electric Corp. Morinaga Milk Industry Co. NEC Corp. (Central Research Labs) NGK Spark Plug Co. Nichirei Corp. NOK Corp. (Research Dept) Seiko Instruments TOA Electronics Ltd. Tsukuba Research Laboratories

(2) Food industry—yogurt fermentation, flesh (particularly fish) freshness estimation, food taste sensing systems, food odor sensing systems, alcohol sensing.

(3) Water monitoring/treatment—residual pesticides, BOD.

(4) Transducer technology—piezoelectric/surface acoustic wave types, optical methods using fluorescence/chemiluminescence, carbon fiber electrodes, Langmuir-Blodgett films and membrane preparation, carbon dioxide detection using a plant leaf sensor.

Philippines

Only one paper was submitted, from the Research Center for Natural Sciences at the University of Santo Tomas, and this reported an optical fiber biosensor based on plant tissues.

Electrical engineering staff members at the university have, over the past 3 years, received training in microelectronic design methods under the Australian ASEAN Economic Cooperative Program Microelectronics Project, and it is hoped that these microelectronics skills will now be applied to advance the biosensor work.

Singapore

Surprisingly, the host country Singapore contributed only a single paper, which was from the Department of Chemistry at the National University. Entitled "A Fiber-Optic Glucose Sensor," the paper discussed a bifurcated fiber-optic probe using an optically active redox mediator coupled to the enzyme glucose oxidase as a means of affording a reversible indicator system for glucose detection in a flow injection system.

While the conference was being held, the Singapore Government unveiled a National Biotechnology Master Plan comprising some $60 million support for projects to boost Singapore's efforts to become a premier biotechnology center in the Asia-Pacific region. Projects include a center within the Department of Chemical Engineering at the university for training in bioprocessing; a separate center for food technology activities aimed at commercializing research in this field; and a center for training and research to be set up within the zoology, botany, and other biological science departments at the National University.

Taiwan

Taiwan also contributed only one paper. This was from the Department of Agricultural Chemistry at the National Taiwan University and was entitled "A L-Glutamate Sensor Using L-Glutamate Oxidase as Biomaterial."

OVERALL COMMENTS

The biosensor area is a relatively new and rapidly expanding field. At present the majority of work has concentrated on glucose sensors; therefore, it is not surprising that there are already a number of important commercial products available, including pocket personal monitors for diabetics. The large number of papers from Europe, the United States, China, and Japan indicates the importance of continued research in biosensors for improvements in sensing traces of biological materials in fields such as medicine, food processing, environmental management and protection, and drug detection. The announcement by the Singapore Government of funding to establish several biotechnology centers and the promotion by many countries (Australia included) of biotechnology as one of the preferred areas of research indicate world interest. At present there is much yet to be learned, for most of the "world" of biosensors has yet to be

conquered. Thus the methods currently employed and areas to which biosensors are applied are limited only by resources and imagination. There are naturally many problems, even in relatively well established areas. Three major ones are sensor lifetime, which in some cases can be only a matter of hours; sensor calibration; and the medical area, in particular, the invasive nature of most sensors.

Thus the first Biosensors Conference was most timely in bringing together workers from so many countries and research fields and allowing them to share in a personal way their experiences. This can only assist in speeding up the development and maturation of this new area.

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COMPUTER MODELING IN THE CONSTRUCTION INDUSTRY-- OHBAYASHI CORPORATION'S RESEARCH LABORATORY

David K. Kahaner

The research structure of the Ohbayashi Corporation is described, with special emphasis on the Computational Engineering Department.

INTRODUCTION

I have been trying to deepen my understanding of the research activities that are performed in Japanese corporations. For the largest companies such as NTT, etc., their work is often reported in English technical journals. But in most other companies their research is less basic and more focused on products and services. If it is published at all it is in company journals written entirely in Japanese. To get a clear picture it is necessary to visit and talk to the research staff, whenever this is allowed.

While reading the Japanese journal *Computer Simulation*, I was surprised by an article about a computer simulation of the Loma Prieta earthquake damage to the San Francisco Bay Bridge that occurred on 17 Oct 1989, complete with three-dimensional color graphics showing the second level of the bridge collapsing onto the first. The article reported that a video of this computation was shown on the NHK TV News Today program and was very well received. The computations were done by the Ohbayashi Corporation at their Technical Research Institute on the outskirts of Tokyo. This provided a good opportunity for me to review the computational activities of this facility, a summary of which is presented here.

DESCRIPTION OF OHBAYASHI CORPORATION

In Japan, construction is the largest industry, accounting for almost 10 percent of the country's gross national product, three to four times that of either automobiles or steel. Anyone who has spent any time in Japan will attest to the astonishing pace of construction activity. The Ministry of Construction estimates that by year 2000 construction will account for ¥50 trillion annually, about $330 billion. Ohbayashi is the sixth largest general contractor in Japan, with current revenues of about ¥1 trillion, roughly $7 billion, in 1989. Larger Japanese general contractors are Shimizu (about 20 percent larger), Taisei, Kumagaigumi, Kajima, and Takenaka. Worldwide, it ranks 11th behind four U.S. companies, Bechtel, Kellogg, Parsons, and Fluor Daniel. U.S. construction companies average 48 percent of their

income from international business, and for Kellogg it is over 70 percent. The percentages for Japanese companies are much lower; Ohbayashi only has 5 percent of its business outside Japan. As of 1988, no U.S. construction contractors had any business in Japan, although Japanese contractors did about ¥200 billion during that year. Ohbayashi provided most of the construction associated with a Toyota plant in Georgetown, Kentucky, as well as a new headquarters building for the Takeda Pharmaceutical Company. Ohbayashi states that "no one has any intention of shutting foreign corporations out of Japanese construction markets. By the same token, they are expected to abide by the mores of Japanese society, as Japanese construction companies have abided by the customs and laws of the overseas societies in which they operate. For Japan's part, any fair competition is welcome as long as the competitors stick to the rules."

Ohbayashi has more than 11,000 employees, including 6,000 with advanced degrees or professional licenses, and more than 200 who are specifically considered research scientists. There are 4,100 architects and construction engineers, 2,100 civil engineers, and 850 mechanical and electrical engineers. Research and development expenditures as a function of revenue are about the same as the other large general contractors, around 10 percent. Research is viewed as crucial to continued success of the company. Y. Ohbayashi, chairman and CEO, states that "in the high-tech, high-info era we live in, intellectual products take on more and more importance. To Ohbayashi this means spending more on R&D, and it means developing better planning and engineering skills."

OHBAYASHI TECHNICAL RESEARCH INSTITUTE

The Ohbayashi Technical Research Institute employs about 300 people: 160 researchers; 100 research assistants and technicians; and 40 management, accounting, secretarial, and support staff. Last year they identified about 440 distinct research projects: 100 associated with basic research, 70 directed at them by the head office (these often mean analyzing a new design), 170 from actual construction sites associated with problems that the on-site engineers could not handle, and about 100 from contract work outside the corporation. The institute has nine major departments:

- Civil Engineering
- Architectural Engineering
- Structural Engineering
- Soil and Building Foundation
- Seismology and Building Vibration
- Environmental Technology
- Acoustic Engineering
- Chemical Engineering
- Computational Engineering

I spent most of my time reading about and speaking to staff in the Computational Engineering Department, but a quick summary of the other departments is given below.

Civil Engineering: Heavy construction, soil structures, seepage, deeply embedded structures, tunneling, offshore structures.

Architectural Engineering: General design, new construction methods, robotization, performance evaluations of new materials and nonstructural materials.

Structural Engineering: Strengths, deformations, design methods for high-rise reinforced concrete buildings, nuclear power structures, coal silos, liquid natural gas tanks, offshore structures, foundations and underground structures, wind environment evaluation of surroundings of multi-storied buildings, earthquake resistance diagnoses.

Soil and Building Foundation: Foundation structures, bearing capacity, setting, liquefaction countermeasures, earth retaining structures, flow properties of bulk solids.

Seismology and Building Vibration: Grounds, structures and ground-structure interaction, vibration hazard prevention, machinery foundations, micro-vibration elimination of super large-scale integration factories, base isolation technology.

Environmental Technology: Facilities and environments in buildings, solar energy, heat storage, energy conservation, rainwater utilization, clean air technologies, studies on laboratory animal facilities, plant factories and building contemplating accommodation of "new media."

Acoustic Engineering: Acoustical designs for studios, music halls, etc.; noise prediction and countermeasures; sound insulation planning.

Chemical Engineering: Materials and property control of slurries, physico-chemical investigations of soils and rocks, soil stabilization, metal corrosion, concrete deterioration and chemical pollution, water treatment by biological techniques, new materials utilization, waste treatment and utilization.

The Technical Research Institute is located in Kiyose City, about 20 km northwest of downtown Tokyo. It sits on 70,000 m^2 of land with about 18,000 m^2 of interior floor space. The facility was opened almost 4 years ago, but Ohbayashi has had a research department since 1948. The institute consists of a main (super energy conservation) office-administrative building designed to use 98.0 Mcal energy per m^2 floor space per year, a center for research in the basic sciences, in-house concrete and soil testing laboratories claimed to be the world's most advanced, a mobile computer center for construction-site data gathering, a barn with 2,000-ton presses for testing concrete column and wall structures, a domed tennis court to display air dome technology, and a High Tech R&D Center. The latter is also called the Base Isolation Building and is claimed to be the first such building actually constructed. It stands on a series of buffer plugs consisting of hundreds of laminated layers of alternating rubber and steel that are designed to stand up under compression but give when shear force is applied. In December 1989 the nearby region was hit by an earthquake that measured 6.7 Richter. The Base Isolation Building was about 100 km from the epicenter. At ground level outdoors a maximum of 44 Gal (1 Gal = 1/cm/sec/sec) was measured, on the roof of another technical institute building (which is not base isolated) 59 Gal was measured, and on the roof of the Base Isolation Building 11 Gal was measured. This is a large five-story building containing, among other things, the Computational Engineering Department. There are several other base isolated buildings that Ohbayashi has constructed in Japan. The first was the No. 1 Shimizu Building in

Shibuya, Tokyo. Another was the Non-Organic Materials Laboratory at Tsukuba Science City. There the system protects an 800,000-power electronic microscope. Seismographic data from all are routed to a computer where the data are routinely analyzed.

COMPUTATIONAL ENGINEERING DEPARTMENT

Most of the technical departments are heavily oriented toward experimental studies and data analysis. The Computational Engineering Department functions as an in-house consultant for them. The manager, who speaks excellent English, is

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The 19 people in this department work in the following areas:

- Structural stress analysis using finite element method (3)
- Dynamic vibration analysis
  - earthquake & building analysis (1)
  - building-soil interaction (2)
  - earthquake propagation (1)
- Soil analysis
  - sinking (1)
  - stress analysis of ground during construction (1)
  - liquefaction of soil (2)
- Fluid dynamics
  - wind pressure (2)
  - environmental, such as air currents inside buildings (1)
  - mathematical analysis (1)
  - ocean waves and offshore analysis (2)
- Acoustics, such as hall analysis, sound pressure (1)
- Space (1)

The group has access to a NEC SX-1EA supercomputer, which is front ended by an IBM 4381 mainframe, located at the company computing center in Tokyo. A network connects the center to the research institute and also about 10 other corporate facilities in Japan. The SX-1's 0.3-GF peak performance is fairly good by today's standards and has been adequate for the group's needs until recently. The 4381 is also used for some analysis work. In addition, there are a number of workstations, mostly Sun 4s, and facilities for producing video tapes. Omote and his staff are well aware of the power of graphics and almost all of their analyses have a graphical presentation associated with them.

The department has installed about two dozen of the most popular engineering analysis packages, such as Abaqus, Stream, Diana-J, etc. It has also developed several of their own packages in acoustics, reinforced concrete member analysis, and soil stress analysis. I tried to get a better understanding of the process involved in developing a new package. Omote explained that the basic "flow chart," or "theory," would be developed by members of his staff. They would also do some of the actual programming. But he admitted that they did not have too much expertise in either the techniques

needed to tailor a program to their supercomputer (vectorization) or the best matrix algorithms for use. In both these cases his researchers can call upon staff at the data processing center. Omote felt that those staff were experts in both areas, although I have had no opportunity to meet with such people. In my discussions with Dr. Omote I tried to explain my own interest in developing better algorithms for solving general classes of problems, for example, to integrate ordinary differential equations. Such algorithms could then go into engineering packages like the ones used in his group. I did not sense much resonance with this kind of work within Omote's department. In fact, I doubt if any of the researchers had significant formal training in numerical methods, although Omote explained that his researchers all know the numerical techniques needed in their fields. A consistent thread that I have observed in discussions with computational research staff at Japanese laboratories is that the scientists are trained in applications. Nevertheless, Omote's group consists of excellent scientists who have done interesting and careful simulations and analysis. A sampling of their technical reports suggests the work that they have done:

- "Nonlinear Analysis for the Design of Nuclear Facility Subjected to Aircraft Impact Loading"
- "Ground Stability Analysis for the Design of Adjacent Underground Tanks"
- "Simulation of Up-Lift Prevention Method of Buried Structure in Liquefaction"
- "Simulation Analysis of Seabed Rock Crushing for Excavation"
- "Prediction Analysis of Subsidence upon Construction of Multi-Storied Building"
- "Analysis of Buckling Stability in Prestressed Concrete LNG Tanks"
- "Simulations of Wind Flow Around Tall Buildings"
- "Analysis for Room Acoustic Design of Ashihala Memorial Concert Hall"
- "Analysis for the Wave Height Distribution Around a Marine Structure"
- "Numerical Simulation of the Trans-Oceanic Wave Propagation of the Chilean Tsunami"
- "Simulation of the Air Flow Within and Around the Skylight Dome"
- "Simulations of Air Flow and Temperature Distribution in a Large Room with Glazed Roof"

Most of these calculations require good engineering insights along with the judicious use of analysis software, or the creation of new software. The staff members are quite capable of producing realistic results quickly. The bridge collapse graphics are a specific case. The modeling techniques Ohbayashi used to produce the graphics that were displayed on TV were very simple. The company obtained analog seismic data that were then digitized. The physical model consisted of two rectangular masses representing the two bridge decks that were connected by springs at their ends and subjected to point forces. Their model was entirely two dimensional; the three-dimensional graphics were generated by projecting the two-dimensional data onto the third depth dimension. A careful examination of the pictures shows this clearly, but TV viewers will have missed it as I did, and as will many scientists. The fact that this simple model has surprisingly good appearance testifies to the physical insight needed

to develop it. Omote readily admitted the crudeness of the model, and also that such a simulation could have been done by any number of researchers both in Japan and the West. But he also pointed out that they were able to generate the simulation in only a few days and display it very quickly. He also showed me a more thorough report on this earthquake that Ohbayashi produced, containing much more careful analysis.

I viewed several videotapes presenting representative work from the Computational Engineering Department. Some of these were in English, although it was not made clear to me why they were produced this way. Omote felt that the other large Japanese construction companies were able to perform similar analyses, although only Shimizu also made use of a supercomputer. In any case he felt that his group did the best work. The tapes showed high quality visual simulations of structures undergoing various types of simulated stress, such as wind, ocean waves, sound pressure, etc. The acoustic analysis of a concert hall was typical, showing "sound particles" issuing from a point source in the center of the stage and bouncing around the hall. The particles were color coded by frequency. This is a typical ray tracing algorithm and it is done in many other design shops. More advanced simulations would allow the designer to interactively manipulate one or more physical parameters, such as baffle dimensions, while watching the results on the computer screen. These are not yet being done at Ohbayashi but there is no intrinsic reason why they could not be done. The fundamental analysis does not change, only the computer programs would need to be altered. And of course, a substantial amount of computer power would need to be available to support this kind of analysis. The SX-1 is fast enough but this depends entirely on the number of particles. The SX-1 should be able to keep up with several thousand particles, but it would have to be carefully coupled to a graphics workstation to provide the bandwidth necessary to transmit all the necessary data.

Omote explained that future research depends to some extent on the interests of his staff, but they want to move toward more fluid simulations, and also do more three-dimensional analysis. Both of these will require additional computing resources and will certainly tax the SX-1, which is already busy.

CONCLUSION

Three-dimensional models lead to complicated matrix and other computational problems. Solving them is not always a simple extension of traditional techniques. New methods are being developed, frequently as a result of strong collaborations between experts in numerical computation and physical scientists. It is usually easy to identify the first group: they read and publish in the computational mathematics journals, attend associated meetings, and are part of a community. I have not seen too much of such work published by scientists here in Japan, nor have I heard much of it during my site visits. As really new computer architectures become commercially available, this pool of expertise will provide a quick-start for applications. The initiation of the new Japan Society of Industrial and Applied Mathematics will provide a significant injection of energy to this field.

Ohbayashi is fairly typical of Japanese construction companies that spend a large fraction of their revenue on applied research. They recognize the need for technology driven research and development to support future projects; many of these are planned 50 years in advance of actual completion. Major future projects are associated with building a city

on the moon by year 2050, a space port in Hokkaido, a bridge/tunnel/highway system that will completely lap Tokyo Bay, and the Yokohama harbor project. The president of Ohbayashi has clearly stated the need for computing and modeling research and expects this kind of work to be vital to the company's long term growth.

David K. Kahaner joined the staff of the Office of Naval Research Far East as a specialist in scientific computing in November 1989. He obtained his Ph.D. in applied mathematics from Stevens Institute of Technology in 1968. From 1978 until 1989 Dr. Kahaner was a group leader in the Center for Computing and Applied Mathematics at the National Institute of Standards and Technology, formerly the National Bureau of Standards. He was responsible for scientific software development on both large and small computers. From 1968 until 1979 he was in the Computing Division at Los Alamos National Laboratory. Dr. Kahaner is the author of two books and more than 50 research papers. He also edits a column on scientific applications of computers for the Society of Industrial and Applied Mathematics. His major research interests are in the development of algorithms and associated software. His programs for solution of differential equations, evaluation of integrals, random numbers, and others are used worldwide in many scientific computing laboratories. Dr. Kahaner's electronic mail address is: kahaner@xroads.cc.u-tokyo.ac.jp.

IBM TOKYO NUMERICALLY INTENSIVE COMPUTATION CENTER AND TOKYO RESEARCH LABORATORY

David K. Kahaner

The IBM Tokyo Numerically Intensive Computation Center is reviewed. This center mainly supports users who wish to develop vectorized versions of programs on IBM's 3090 VF computers. The Tokyo Research Laboratory performs longer term research in computer science, mathematics, graphics, and languages.

INTRODUCTION

IBM is such a large international organization that no effort will be made to survey their overall research activities but only to describe the research organizational structure and the work performed at the Tokyo Numerically Intensive Computation (NIC) Center and, even more briefly, to describe the major directions of research at the Tokyo Research Laboratory.

Some of the most famous computational research in IBM is done at their "research laboratories" such as the T.J. Watson Laboratory in Yorktown Heights, NY, and equivalent laboratories in Zurich, Palo Alto, and Tokyo. The first three are well known and need no further discussion. IBM also supports a collection of scientific centers, mostly containing system specialists who work directly with users. These are in the United States, Norway, the United Kingdom, Italy, France, Spain, Israel, Kuwait, Egypt, Mexico, Venezuela, Tokyo, and Brazil. To build applications IBM also has five "competence centers," each of which is specifically tasked to provide research and support in a target area. There are two competence centers in the United States, at Yorktown Heights, NY, and Almaden, CA; one in Heidelberg, Germany; one in Stavanger, Norway; and one in Winchester, United Kingdom. The Stavanger Center, for example, focuses on environmental modeling.

IBM TOKYO NIC CENTER

There are also four NIC centers: in Kingston, NY; Palo Alto, CA; Rome, Italy; and Tokyo, Japan. These are a recent invention; the Tokyo center has been in existence only since 1988. The NIC centers were specifically created to provide more scientific expertise than is available at the scientific centers and to provide support for users who are doing scientific computation, primarily on IBM's VF (Vector Facility) 3090s. The staff at the NIC centers do research that is directly in support of current applications, such as vectorization techniques. For example, the IBM

NIC center in Rome produced a 3090 vectorized version of the well known crash analysis package PAM. Horizons at the NIC centers are a few years ahead, rather than 5 to 10 years as might be the case at the research laboratories.

NIC centers provide support in application and system areas. Application areas include:

- Structural analysis
- Fluid dynamics
- Electronic design
- Financial investment planning
- Computational chemistry
- Nuclear engineering*
- Meteorology and oceanology*
- Seismic and reservoir analysis*
- Optimization and mathematical analysis

System areas include:

- Languages
- Parallel and vector processing
- AIX (IBM's version of Unix)
- Graphics and image processing
- Workstation-mainframe interaction
- Distributed computing

The Tokyo NIC Center has 19 scientists who have expertise in all these areas except those marked with asterisks (*). Recent technical reports and papers from the Tokyo NIC Center (see below) reflect their activities very well. Aspects of this work that might interest western scientists include a survey of large scale integration (LSI) simulation software, a combined simulation of gas flow in the intake port, valves and cylinder of an automobile engine (the integration of these had not been done before), parallelization of a well known computational chemistry code, a study of a vectorized version of PROLOG, and research with the ACRITH system. The latter has been popularized in the United States by Professor L. Rall and is associated with interval arithmetic and self-validating algorithms, i.e., when numerical output also comes with an interval in which the correct results are guaranteed to lie.

The Tokyo NIC Center has various joint studies with industry and universities. For example, vectorization of PROLOG was done in conjunction with Waseda University, and the automobile engine simulation was done jointly with Mazda. The NIC centers are also used as training grounds for IBM software engineers. When appropriate, the Tokyo NIC Center also works with scientists at the Tokyo Research Laboratory. Both are in Tokyo about 15 minutes apart by subway; the Research Laboratory is near the Imperial Palace and the NIC center is near the Tsukiji fish market. I asked about the multiprocessor, TOP-1, that I saw early this spring. This was built at the Tokyo Research Laboratory as an exercise in the creation of such a system, but the NIC center staff developed the application software for the demonstration that I saw. The Tokyo NIC Center Manager is:

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Tokyo NIC Center
IBM Japan, Ltd.
18-24, Tsukiji 7-chome
Chuo-ku, Tokyo 104 Japan
Phone: (03) 546-4376

Hosoi and Akira Okuda [(03) 546-4328] explained to me that the Tokyo Research Laboratory is primarily focused on computer science (see below) rather than on the applications of the NIC center. Okuda and Hosoi expressed the usual respectful frustration about researchers who do not have to deal with real user problems. When I commented that their center seemed quite small for so many projects, they agreed and claimed that they are always trying to get additional staff. There is

plenty of computing power, though. The NIC center has one 3090-60E 6VF, one 3090-30S 3VF, a 3090-30J 3VF, and four 5080s. The six-processor 3090 has 512 MB of memory and 1 GB of external storage.

I spent several hours with Okuda discussing the types of users they encounter. He explained that scientists at universities and research institutes typically create programs, while those at companies prefer to run packaged products written elsewhere. This certainly fits with my own observations. Okuda would be happier if everybody ran canned software, but he noted that IBM provides a subroutine library composed of highly vectorized routines to support programmers. I am very familiar with this product (ESSL), and it is true that a great deal of work has gone into the tuning of its contents. Fortran is the language of choice for 3090 users. IBM has provided many extensions to take advantage of the vector instructions available on the VF machines and also Parallel Fortran, which allows multiprocessing. Current 3090 VF machines can have up to six separate processing units. Parallel Fortran also has the ability to permit more than one 3090 to cooperate. Research on this is being done at Cornell University in collaboration with the IBM center in Kingston. (Cornell's supercomputer center is the only IBM center of the six set up through the National Science Foundation.) Parallel Fortran is not yet a commercial product; testing is being done at various IBM installations including the Tokyo NIC Center. There is a growing interest in other languages, such as C and PROLOG, within the scientific community in Japan, but the user pressure in this direction is still quite modest according to Okuda.

Although the NIC center is very clearly focused on direct user applications, this was one of the few places I have visited in Japan in which numerical analysis is recognized as a separate entity. In fact, Hosoi and Okuda showed me the organization chart for the NIC center that specifically listed numerical analysis at the center between computer technology and applications. As an example, the work on ACRITH is presently far removed from direct applications.

As part of some formal presentation materials I was given by Hosoi was a sheet describing the Tokyo NIC Center "spirit." This was shown as a poker hand of five cards: four aces (active in technical support, ahead in expertise, accord with future market requirements, and attention to future technical trends) and one joker. This was to signify not only a wild card but also that the joker is a jolly fellow. This differs from the usual IBM image, certainly in the United States, but agrees well with the remarks about managing people that were repeatedly made at the Software Quality Workshop in Kyoto that I reported on in the previous issue of the *Scientific Information Bulletin* ["Second International Workshop on Software Quality Improvement: Summary and Assessment," 15(3), 31-37 (1990)].

IBM TOKYO RESEARCH LABORATORY (TRL)

This is composed of three departments: the Computer Science Institute, the Advanced Technology Institute, and the Tokyo Scientific Center. The Director is:

Dr. Norihisa Suzuki
IBM Tokyo Research Laboratory
IBM Japan Ltd.
5-11, Sanbancho
Chiyoda-ku, Tokyo 102 Japan

I met Dr. Suzuki last December when I visited TRL with Professor Gene Golub of Stanford University. (Suzuki is a graduate of Stanford's Computer Science Department.) At that time Suzuki explained that most of

their research is computer science, rather than numerical, in nature, with an emphasis on graphics and interfaces. They have a number of reports but most are for internal use only. The following summary of TRL research activities is from printed material and brief discussions with some staff.

The Computer Science Institute (CSI) performs research in basic information science. They build workstation hardware and multiprocessing hardware such as the TOP-1 system mentioned above. They also perform research on software for small scale parallelism and concurrent languages. Research is also being done on speech recognition and Japanese text entry, as well as analysis of human cognitive processes with an eye toward building human-friendly interfaces. Some research is also occurring on multimedia applications, such as document systems and databases that contain text, graphics, and voice. Theoretical work on the fundamental problems in computer science using queuing theory, stochastic processes, complexity theory, and computational geometry is also being studied. Finally, work is going on in the area of PROLOG compilers and other programming languages.

The Advanced Technology Institute (ATI) is primarily interested in manufacturing technology and automation.

The Tokyo Scientific Center (TSC) is also part of the Tokyo Research Laboratory. Staff in TSC work in the areas of image processing, pattern recognition, graphics, machine translation, and natural language interfaces.

RESEARCH PAPERS AND REPORTS FROM IBM TOKYO NIC CENTER

"Parallel/Vector Processing and Ease of Programming," 4th Symposium on Vector Processing Computer Applications, A. Okuda and Y. Aoyama (1988).

"High Speed Computing by Multi-Tasking," 36th Japan Information Processing Society Conference, Y. Sugiuchi (1988).

"Some Experiments on New ACRITH - Internal SOR Algorithm," Special Meeting on Self-Validating Algorithms and Applications, A. Okuda and Y. Tanamachi (1988).

"IBM 3090 Vector Facility and its Applications," Japan Society of Systems Engineering, A. Okuda (1988).

"An Example of Effective Use of Large Storage on High-End Computers," 37th JIPS Conference, Y. Sugiuchi (1988).

"Study of Computational Fluid Dynamics Simulation with SOLA-3D," TR88-002 (1988).

"Self-Validating SOR Algorithm," Mathematical Society of Japan, A. Okuda (1989).

"An Efficient Implementation of Device Simulation on the IBM 3090 VF," PR89-001 (1989).

"Survey Report of LSI Simulators," TR89-003 (1989).

"Report of Joint Study with Waseda University," PR89-003 (1989).

"Numerical Simulation of Port-Valve-Cylinder Flow in a Reciprocating Engine," Society of Automobile Engineers, M. Fujiwara and M. Hongoh (Mazda), E. Tamura and S. Obana (IBM), S. Aita, A. Tabbal, and G. Munck (ESI) (1990).

"Parallelization of Computational Chemistry Code ATOMCI," 6th Large Scale Matrix Calculation Symposium at Keio University, A. Hasegawa and N. Honjou (IBM), K. Ohtsuki, M. Sekiya, and F. Sasaki (Hokkaido University) (1990).

"Quadratic Programming and Vector Performance," TR89-001 (1989).

THE 10TH SOFTWARE SYMPOSIUM

David K. Kahaner

The 10th Software Symposium, held in Kyoto, Japan, from 6 to 8 June 1990, is briefly summarized. The most interesting aspects were discussions by the Chinese of their national project.

INTRODUCTION

Although this meeting's call for papers was in English, and the official languages of the meeting were English and Japanese, all of the nearly 60 papers were presented in Japanese, except for the Opening Session, by Professor Gerhard Fischer from the University of Colorado. Almost 300 scientists registered for this meeting; about 10 were from China. Fischer, his colleague Professor Andreas Lemke, and I were the only western attendees.

Mr. Nobuaki Higashi, from Fuji Film Imaging and Information, Technical Development Center, provided several pages of notes about the Japanese sessions that he attended. Professor R. Schlicting, University of Arizona, who is visiting Tokyo Institute of Technology this year, also provided important comments and corrections.

Fischer's speech was translated into Japanese, as were the talks by the Chinese attendees. (Although Japanese and Chinese use the same kanji characters for writing, the spoken languages are completely different, and most Japanese cannot understand spoken Chinese.) The Chinese scientists all could speak English, but unfortunately they did not take advantage of this for presentations at the meeting. When I asked why more translation services were not provided, the conference organizers explained that in the past this had been a regional meeting and, in fact, this was the first year it was being held outside Tokyo. Fischer also had language problems. In fact, he was asked to make a few comments at the conclusion of the meeting on the future role of Japan's software work, but he admitted that he did not really understand what the major activities were and concentrated instead on more general themes.

COMMENTS ON OPENING SESSION

Fischer's opening presentation described the work that his group has been doing for a number of years. His main idea was the need to move from "downstream" to "upstream" tools. By that he meant tools more focused on the problem domain rather than on converting from formal specifications to programs. He also felt that much more emphasis must be given to tools that the user (rather than the software developer) can modify, what he called "participatory design." He used, as example, a system for kitchen designers built by his group. Fischer envisions movement toward a construction kit by which the user could easily make the application by him/herself and then beyond that to a knowledge-based construction kit. For example, in the kitchen design, after laying out the stove-sink-refrigerator the system should evaluate the user design and

provide comments such as "the stove is near the refrigerator, here are the pros and cons of that."

To a numerical person like myself many of Fischer's general comments appeared to be perfectly correct. For example:

- "Just like good writers cannot write books about subject domains which they are not familiar with, good software engineers cannot write programs for domains which they do not understand."

- "Requirements are never complete. ... Requirements are poorly understood because clients do not know what they want and without a partial exploration of the problem space, the defining characteristics of a complex artifact are difficult (if not impossible) to generate."

- "Formal specification techniques face the problem that what designers and users do and know to a great extent has to be experienced in practice. [Perhaps an] insignificant part of design knowledge can be expressed in verbal descriptions as propositional knowledge."

- "Complex systems are not designed from scratch, but they evolve. ... The analysis of breakdowns leads to a deeper understanding of the shortcomings of designs."

Apparently software engineering went through a period where people hoped that most problems could be solved adequately with very general tools and techniques even though it was obvious to everyone that a very specialized custom tool would always do a better job. Seeing that this general approach was not 100% effective, the emphasis has moved more to the "meta" level, where people look at constructing tools that can be used to produce other (more custom) tools. One analogy here might be in the area of user interfaces (UI), where the research moved from straight techniques for constructing UI to so-called user interface management systems (UIMS), which are systems that attempt to automate the construction of UI.

Fischer emphasized that much of his work ignores important aspects of some software projects, particularly large project teams, time constraints, management of the software process, hardware costs, software quality and testing, and elaborate external specifications. In particular, for the last item he pointed to Department of Defense software projects that are built on complicated external specifications and stated that he thought that these worked poorly because they were too document driven.

Fischer also emphasized the need for problem solving systems that work in conjunction with people rather than as replacements for them. This echoed some aspects of the next Ministry of International Trade and Industry (MITI) project on flexible software systems.

DISCUSSION OF SYMPOSIUM PRESENTATIONS

The meeting was organized around four parallel sessions; one of these was used for software "tool" demonstrations. Most of the demonstrations were of modest research projects. For example, a group from Kobe University demonstrated a system to manage video databases using Hypercard and Hypertalk on a Mac II. Data can be not only text or static images but animated images as well. Even the icon for the image can be animated. Higashi informed him that several large Japanese corporations such as Fuji, Toshiba, and others were engaged in a major patent fight on this issue. A few of the software tool demonstrations were sales pitches, such as the one by the representative of Mitsui-Bank software.

Frankly, I objected to senior researchers being given half an hour for a technical talk while some demonstrators had an hour or more use of a room for sales presentations. Nevertheless, this was a minor annoyance.

There were several "panels" consisting of three or four people discussing a specific topic. In one, "Effectiveness of CASE," the United States and Japan were directly compared by breaking CASE (computer-assisted software engineering) activity into five stages.

(1) Disenchantment (new technology and tools needed)

(2) Resignation (tools are useful and probably necessary)

(3) Commitment to new methodology (methodology does not equal tools)

(4) Implementation (realization that additional resources are needed)

(5) Maturity (realization that one methodology is not enough)

The panel felt that Japan was working in the range of (1) to (3) while the United States was somewhere between (3) and (5).

The most interesting session was also a panel, titled "CASE in China." Four Chinese scientists presented their perspectives. Of these two deserve special summary: (1) EASYCODE and (2) SEP, the Chinese national Software Engineering Project.

EASYCODE was described by Zhou Shanqiong, who holds a joint position at the East China University for Chemical Technology and RISE (Rapid Information System Engineering Corporation), a small company working on CASE tools. He explained that CASE work in China was at the juvenile stage, with work only beginning in 1983-84. Nevertheless, there was a large research and development (R&D) effort underway associated with SEP. Now, CASE tools were mostly written in C language, and still primarily for internal use. There are yet no mature products. However, there was growing interest in the Government because of their sense that users want software tools and that a large market existed. CASE tools run mostly on PCs, Vax, Sun, and on other X-windows systems. In the specific instance of his company, RISE produces a CASE environment called EASYCODE, designed for data processing professionals or perhaps management information system projects. It is currently in its second generation, with more than 80 man-years of effort expended on its development. Various software paradigms are built in, such as life cycle analysis, object-oriented design, etc. The new version also supports multiple users. EASYCODE allows users to define interfaces, develop activity profiles, and build forms. Its largest use is in support for the 1990 Asia Games. This is a large-scale project, with more that 28 different athletic events, over 10,000 pages of specification documentation, pressing schedules, and constantly changing requirements. About 60 man-months have been devoted to this (not many), but almost one million lines of C language code have been produced. Shanqiong also provided some statistics of the effectiveness of EASYCODE—about 16 thousand lines of code per man-month, 60 Albrecht function points per man-month, and about 250 lines of C per function point. Most importantly, he emphasized that for the future they expected to take advantage of the built-in Chinese character set to produce a highly marketable product. Finally, he emphasized his desire for a joint venture product with Japan. A Japanese colleague remarked that this seemed a rewrite onto a workstation

from Prolog to C and that nothing new was accomplished. I believe that criticism is too strong.

SEP is a large-scale national software project begun in 1986 and funded by the Chinese Government. There are nine groups that are principal investigators, including the following, although many others have some research role.

- Beijing Institute of Technology
- Beijing University
- Institute of Software Academia
- Fudan University
- Beijing University of Aeronautics
- Chinese Software Technology Company
- Shanghai Software Center

The speaker, Zhow Xling, explained that coordination with so many different groups caused expected problems, but that the Government wanted to support large research projects and additionally felt that the increased participation would be good for all the research establishments in the long run.

Stage I (1986-90) focused on the development of tools and investigating tool integration. Stage II, which is beginning this year, will work toward actual integration of the tools previously developed. Specific activities have been in the following areas:

- Requirements analysis and design tools such as editors
- Testing and configuration controls
- Program understanding and maintenance
- Information-based integration
- Host systems based on Unix modified for Chinese characters
- Man-machine interfaces
- Leverage, i.e., promote use by users
- New technology tools research
- Importation of foreign tools

Xling explained that in 1990 the hope was to perform three tasks. In all of this, the working language is C.

(1) Build a prototype integrated environment for a Sun workstation, but not including all the developed tools.

(2) Build a software tool package for 386-based systems.

(3) Collect together all the diverse tools that are now on different machines.

In the near future the project hopes to work toward the following:

- Develop a marketable product.
- Work toward standardization, perhaps using the European PCTE (portable common tool environment) standard.
- Negotiate with the Japanese to use the same industry standard and the same software tools.

A major problem seems to be that the representation of kanji characters differs in Japan and in China. I reported earlier that Sony uses its own representation and there are several others in Japan as well.

Several interesting issues were raised at the panel "Software Maintenance and Assistance Environment in the 1990s." The panelists were Miyamoto, (University of Hawaii), Sata (Nagano prefecture Joint Computing Organization), Urano (KCS), Tanaka (Yamaichi Securities), and Yatsuyanagi

(Sumitomo Kinzoku). Miyamoto emphasized the difference between developing software and maintaining it and the need to discover what kinds of documents are necessary through the whole life cycle of a system. We have all seen examples of software with poor or non-existent documentation, even though documentation problems have been "the issue" for 10 years. Nevertheless, even professionals tend to weigh development more highly than maintenance. Miyamoto felt there was a need for tools that would generate reports and documentation from program source code—what he called "reverse engineering." I personally believe such an approach will only produce stylized documents that cannot be read. Perhaps it would be better to have tools that automatically generate documentation in parallel with development. Miyamoto and the other panelists also expressed a pessimism that the products of human beings will always be incomplete because humans are incomplete. He also worried about software skills being eliminated from end user companies as more and more software was pushed off onto software shops.

Several software houses described how they struggle with maintenance problems and see no real solution in sight. Their approaches were often quite different. One company requires beginning software staff to work at maintaining software written by more senior staff. They feel that learning this skill is important because so much time will be spent over their career on maintenance. Another company's representative stated that freshmen work on development because maintenance is too difficult and needs the skills of more senior people. (Somehow I doubt that this is really the way their system operates.) Finally, a representative from Oki claimed that the only documentation needed was comments in the source program. This was considered heretical by most of the other speakers and listeners.

COMMENTS ON CLOSING SESSION

The symposium's closing session was a panel titled "Global Role of Japan in the Information Age," chaired by Professor H. Wakita of Osaka University. Wakita presented a spirited talk organized around his view of historical world dominators:

1550	Spain
1600-1700	Netherlands
1830-1900	Great Britain
1950-1970	United States
1990-?	Japan
?-?	United States or Europe

He said "the age of U.S.A. is over. Now it's Japan. We are going to spread the Japanese way all over the world." It was clear that he felt that Japan had to capitalize on its strong economic role and that information technology was the key to economic success. On the other hand, Dr. T. Matsubara from Hitachi asked the question, "Is Japanese software superior to U.S.?" He felt that at this time the answer was "no" for reasons such as the following:

- Structured analysis was not popular among practicing software engineers.
- The "waterfall" model was the only process being used in practice.
- Documentation and diagramming rules were chaotic.
- There is little use of electronic mail, and in general communication between scientists is thin.
- Most software systems are still written in COBOL.

- There is a weak demand for an open user platform and current platforms are highly segmented.

- A recent survey of users showed that 54% have never heard of COCOMO, a method for modeling software cost based on a number of different parameters.

- Japanese text causes difficulties.

- There are relatively few forums for discussion of software issues.

- There are no uniquely Japanese software methodologies.

I am not sure if the majority of symposium participants agreed with him; perhaps this was simply a case of noticing the problems inherent in any large and multifacited activity. Electronic mail, for example, is still not as heavily used in Japan as in the United States, but users are rapidly changing to this mode of operation. In any case, Matsubara felt that Japan's software professionals needed to take two major steps:

(1) Invent ways to deal more tangibly with software by focusing even more heavily on commercializing. The point here was that Japan is clearly good at this aspect and should build from its strengths.

(2) Standardize to make software development tools easier to move. Given the closed nature of many Japanese corporations, this is going to be the more difficult step.

Miyamoto (Univ. of Hawaii) ended with a little joke. "Through many experiences I have discovered this: An American can explain that it was not his fault when a project fails. A Chinese works hard but no one can understand what he is doing. Indians and Pakistanis each have their own opinion and cannot get along with the others. I can't say about Korea because the relationship between Korea and Japan is now delicate [the President of Korea has just visited Japan]. Hawaiians don't work. So I think the best bet for tasks in a team project is—U.S.A. plan, Japan provide the money, China write the programs, Korea test, and when they get tired the Hawaiians sing and cheer them up."

TITLES AND AUTHORS OF PAPERS

Opening Session

Prof. Gerhard Fischer, University of Colorado
"Cooperative Knowledge-Based Design Environments for the Design, Use, and Maintenance of Software"

Session 1A: Software Process

"Modeling & Prototyping of the Project Management Process"
M. Ino, Software Research Associates & Software Engineering Laboratory

"A Mechanism for Adapting Dynamic Features in Software Processes"
T. Ohta, T. Yamaguchi, and K. Ochimizu, Department of Computer Science, Faculty of Engineering, Shizuoka University

"A Process Description Model Based on Objects"
T. Ogihara (Education Center for Information Processing, Osaka University); H. Iida, K. Inoue, and K. Torii (Faculty of Engineering Science, Osaka University); and J. Okiu (Faculty of Engineering, Nagoya Institute of Technology)

Session 1B: Formal Approach

"An Implementation of Order-Sorted Term Rewriting"
T. Sawada and K. Futatsugi, Electrotechnical Laboratory

"Description and Implementation of File Management System Using Attribute Grammar"
T. Imaizumi, Y. Shinoda, and T. Katayama, Department of Computer Science, Tokyo Institute of Technology

"Two Algebraic Specifications of a Process Control Program and Their Relations"
J. Okui (Nagoya Institute of Technology) and M. Fujii and K. Taniguchi (Osaka University)

Session 1C: Requirement Analysis

"Evaluation of the Card-Handling Tool KJ-Editor"
M. Koyama, K. Kawai, and H. Ohiwa, Toyohashi University of Technology

"A Specification Methodology Based on Stepwise Refinement of Data Structures"
T. Oda and T. Katayama, Department of Computer Science, Tokyo Institute of Technology

"YARN for Yet Another Requirement"
Y. Yamamura, IBM Japan, Systems Laboratory

Session 2B: Testing and Debugging

"Prolog Type System and Its Application to Algorithmic Debugging"
T. Hama, IBM Japan, Tokyo Research Laboratory

"A New Debugging Tool Based on Dynamic Slicing Concepts"
Zhang Ran and Nie Shixue, Department of Computer Science, Fudan University, Shanghai, China

"Optimum Test Case Generation for Programs without Loops"
M. Ohba and A. Adachi, IBM Japan, Tokyo Research Laboratory

Session 2C: Software Development Environment

"A Design Document Understanding Method Using a Decision History Storing System"
K. Shima, NTT Software Laboratories

"A Software Modification Support System Using Interaction Information"
H. Yamada (Ehime University) and Y. Tezuka (Osaka University)

"M-Cube: Environment System for Multi-Media Knowledge-Base Systems"
T. Onoda and M. Suzuki (Central Research Institute of Electric Power Industry), T. Terano (University of Tsukuba), and K. Uenishi (Kansai Electric Power Company)

Session 2D: Object-Oriented Approach

"Integration Process in Object-Oriented Programming Environment"
J. Aoki, Fuji Xerox Information Systems Co. Ltd.

"An Upper CASE Tool 'PWB' (Programmers Work Bench) with Object-Oriented Programming"
K. Shioya and K. Watanabe, Software Research Associates

"A Method of Object-Oriented Design in Communication Control Software"
K. Noguchi and M. Ito, NTT Mobile Communications Division

Session 3A: Database

"EASYDB - A DBMS Prototype for Managing Hierarchically Organized Data"
C.F. Liu, Z.L. Gong, M. Yu, and W.J. He, Rapid Information Systems Engineering Corporation (RISE), Shanghai, China

"Object Management System for Software Requirements Analysis"
Y. Kato, PFU Limited

"A Data Model for Software Object Management System and a Prototype System Based on the Model"
L. Williams, Software Engineering Research Inc., Boulder, CO, and Software Research Associates Inc., Boulder, CO

Session 3B (Panel): CASE in China

Panelists: Cai Linxi (East China Research Institute of Computer Technology), Hao Kegang (China Northwestern University), and Ju Dehua & Zhu Sanyuan (RISE)

Session 3C: Software Quality Techniques

"On a Software Reliability Evaluation Based on Time-Dependent Behavior of Testing Domain"
H. Ohtera (Okayama University of Science) and S. Yamada (Hiroshima University)

"Analysis of Fault Introduction in Program Development by JSP Method"
Y. Mohri (Education Center, Kansai Regional Head Office, Nihon Unisys Ltd.) and T. Kikuno and K. Tokii (Department of Information and Computer Sciences, Faculty of Engineering, Osaka University)

"Experimental Evaluation of Metrics for Review Activities"
S. Kusumoto, K. Matsumoto, T. Kikuno, and K. Torii, Department of Information and Computer Sciences, Faculty of Engineering Science, Osaka University

Session 3D: Knowledge Base

"Partial Information Problems and its Processing Method on the Knowledge Processing—As the Example of Natural Language Processing"
K. Hirai, Japan Information Processing Service Co. Ltd., Osaka Branch

"A Method of Knowledge Acquisition for Expert Systems"
H. Masumoto, S. Ishimoto, T. Chinen, K. Okuma, K. Koyama, H. Oka, Y. Nishimura, H. Iwaki, T. Matsubara, T. Yamauchi, K. Kajiwara, and M. Hayakawa, Mitsubishi Electric Software Co.

Session 4A: Reuse

"Promotion of Software Reusability by Using Reusable Software Data Base"
A. Takahashi, Mitsubishi Electric Computer Systems (Kansai) Co. Ltd.

"CATALOG EXPLORER: Exploiting the Synergy of Integrated Design"
K. Nakakoji and G. Fischer (University of Colorado, Department of Computer Science) & (Software Research Associates, Japan)

Session 4B: Methodology

"A Software Synthesis Paradigm Based on Model Combinations and Design Information Live-Time"
M. Hashimoto, T. Takenaka, and K. Yamashita, ATR Communication System Research Laboratories

"A Design System VD/RCS for Real-Time Software—Improvement of Reliability and Execution Speed"
J. Miyao, H. Hamamura, K. Hatta, S. Wakabayashi, and N. Yoshida, Faculty of Engineering, Hiroshima University

"Making a Functional Programming Language Applicable to Software in the Large"
M. Nitta, Software Research Associates, Software Engineering Laboratory

Session 4D: Hypertext

"A Chart Editing System for Analysts and Programmers"
A. Shiomi, K. Kawai, N. Takeda, and H. Ohiwa, Toyohashi University of Technology

"The Auto Layout with Hypertext/Media System"
T. Baba and H. Nakano, Department of Communication Engineering, Faculty of Engineering, Osaka University

Closing Panel: Global Role of Japan in the Information Age

Chair: Prof. H. Wakita (Osaka University); Panelists: G. Fischer, H. Fukase, T. Katayama, K. Kishida, T. Matsubara, and I. Miyamoto

ELECTROTECHNICAL LABORATORY DATAFLOW PROJECT

David K. Kahaner

A visit to the dataflow project at the Electrotechnical Laboratory is summarized. The dataflow SIGMA-1 computer project is ending. The new project, EM-4, will have 1,024 processors and is designed to have less overhead. EM-4 was originally proposed for symbolic rather than numeric computation, but the designers now feel that with the inclusion of floating point hardware it will also be used for numerical computation. Currently an 80-processor version of EM-4 is running at 997 MIPS.

INTRODUCTION

On 28 March 1990, Dr. Bill Buzbee [National Center for Atmospheric Research (NCAR)], Prof. Jack Dongarra (Univ. of Tenn.), and I visited the Computer Architecture Section of the Computer Sciences Division at the Electrotechnical Laboratory (ETL) in Tsukuba. I had been to Tsukuba several times earlier, but never to ETL. ETL is the largest national research institute in Japan, belonging to the Agency of Industrial Science and Technology (AIST) of the Ministry of International Trade and Industry (MITI). As a national laboratory it is surprising that it only has about 700 employees and a 1988 budget of around $70M. More surprising still is that about 550 of the employees are members of the research staff; only about 150 are general or administrative staff. In fact, Buzbee remarked that NCAR also has about 700 employees, but the ratio of scientific to nonscientific staff was almost exactly reversed there. I am familiar with other U.S. laboratories, and the NCAR ratio is similar to those. Thus the ETL scientists must be remarkably self-sufficient or their counting process differs from ours.

ETL will be 100 years old next year, beginning as a testing laboratory under the Bureau of Electrocommunication. Its current charter is to perform basic research and development in electronics, information processing, energy technology, and standards and measurements. Emphasis is placed on the development of technologies that exert impact on society and industry and that are so advanced that they require long time and substantial risk to attain their goals.

DESCRIPTION OF THE DATAFLOW PROJECT

The activities of ETL that are directly computer related are contained in the Information Sciences Division, Computer Science Division, Machine Understanding Division, and Intelligent Systems Division. Together these groups contain 120 researchers. A major

project of the Computer Science Division has been the construction of the dataflow computer, SIGMA-1, and its follow up the EM-4.

Scientists who are working on this project include the following:

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Technical reports about the ETL dataflow project are available by contacting Dr. Sekiguchi.

In addition to the dataflow group, we also met with the ETL Director

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and the directors of the Information Science and Intelligent Systems Divisions

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SIGMA-1 has been extensively written about—it is not a new project and it is ending this year—so we were mostly interested in learning about their more recent work. An excellent summary of dataflow, specifically oriented toward the ETL dataflow SIGMA-1 project, was written by Shimada, Hiraki, and Sekiguchi of ETL and then translated to English by Mr. C. Eoyang of the Institute of Supercomputing Research (ISR) in Tokyo. This translation, which I used heavily in writing this report, was published in *Vector Register* (15 November 1988). Contact Eoyang at:

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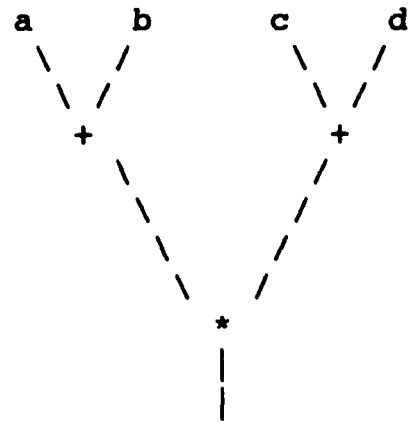
In principle, the dataflow idea is very simple, that an instruction should execute whenever its data are available. As a prototypical example,consider the computation (a+b)*(c+d). Such a computation could be broken into a "dataflow graph" that looks like the following:



A computation begins at one of the + or * points (called nodes) whenever a token appears, signifying that data are present on an input line. The node "fires" (arithmetic operation is executed) when all input data are available. At that point all input tokens are removed and a token is placed on the output line. Obviously in this model many other computations are independent of this one; thus many nodes can fire simultaneously. Various enhancements are necessary for this model to work in practice; these have to do with making best use of the dataflow graph once it has been created and allowing parallel and loop operations to be executed. In the SIGMA-1 project these enhancements are called "dynamic computational model." The key research projects are associated with implementing this model in practical hardware and designing and implementing user-usable software that can take advantage of the hardware.

The SIGMA-1 project ends this year. The EM-4 project is a follow-on that attempts to build on what was learned earlier. The main emphasis is to simplify the total architecture by putting several processing elements onto a single chip with a simplified network structure. The ETL group also decided that some modifications of the "pure" dataflow model were necessary to efficiently match the machine with real programs and get maximum performance from it. In the context of a dataflow graph, it was observed that no strategy was proposed to permit maximum utilization of the processing elements by detecting possible critical paths and scheduling the computation so that work along these paths had priority. The new model, called "strongly connected arc model," attempts to remedy this by allowing certain portions of the dataflow graph to be performed in a more or less traditional way.

As part of the project the ETL group is developing a C-like language, DFC-II, which is only partly a functional language. Using traditional functional languages, it is difficult to write programs for the utilities that are necessary in practical programs, such as writing synchronization, resource management, and global variables. DFC-II was not running when we visited, although we've been informed that it is now up on the EM-4. Lack of software has been criticized (see below), although this year the group's emphasis has shifted toward software development. Dr. Shimada explained that the group plans to complete the compiler work by autumn and then begin to evaluate the architecture on practical application programs. He also noted that at some point the group will also develop a functional language.

SIGMA-1 was specifically designed for numeric computation. The new machine EM–4, as originally described, had no hardware to support floating point. In fact, in several papers Yamaguchi et al. say that their field of interest has shifted away from numerical to symbolic manipulations involving knowledge information processing. Thus this machine was less interesting to me as a computer that would support simulation research, and I sensed that Buzbee and Dongarra had similar feelings.

However, Dr. Sakai in the dataflow group has recently told us that floating point will be included in the 1,024-processor version, which will then be able to perform at about 20 GFLOPS. Their vision is that EM-4 will also be suitable for numerical computation.

CONCLUDING REMARKS

Neither I, Buzbee, nor Dongarra are experts in computer architecture. Mr. Olaf Lubeck, a researcher in the Computer Research and Applications Division of Los Alamos National Laboratory, also visited ETL late last year. His research is directly related to the work at ETL and this was his second visit to the dataflow laboratory. I asked him to provide me with a short assessment of that visit, a portion of which is included as an appendix. I am indebted to him for this effort. My personal impression is more positive than his. Despite the difficulties that have slowed progress, one should realize that more than a decade of research was necessary to reach the level we see today and that many fundamental problems had to be solved. The group is remarkably productive. In fact, we were quite astonished at how few people were actually working on this project. It is a very small group working without the assistance of many students and, based on my statistics above, with only limited administrative support. Nevertheless, their research is of long term interest. They are building a "real" dataflow computer, neither a software simulator nor a hardware simulator. Currently, an 80-processor version has been built; it performs at 996 MIPS. Dr. Shimada told me that preliminary evaluation on small benchmark programs shows that the performance is 15 to 100 times faster than a Sparcstation 330. The design allows for 1,024 processors and this is the next project. I would not be surprised to see some attempt to commercialize it.

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Yamaguchi, Y., S. Sakai, K. Hiraki, and Y. Kodama (1989), "An architectural design of a highly parallel dataflow machine," in *Proceedings of Information Processing '89*, G.X. Ritter, editor (Elsevier Science Publishers, North Holland), pp 1155-1160.

Appendix

PROGRESS OF THE ELECTROTECHNICAL LABORATORY DATAFLOW PARALLEL COMPUTER PROJECT

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I visited the Electrotechnical Laboratory (ETL) for 3 days in December 1989. While there, I discussed mutual interests in dataflow research with the group. The group consists of three sections built around one of three different machines. The first section is investigating the SIGMA-1 tagged-token dataflow machine. The machine was completed about a year ago. It consists of 128 processors, is a "pure" operational level dataflow machine, and is modeled after the Massachusetts Institute of Technology (MIT) tagged-token dataflow architecture. Since my last visit a year ago, little progress has been made to allow the programming of the machine from a high-level language. The intent of this effort has been and still is the development of a C-like language called DFC-II. The language is imperative and contains explicit synchronization to allow user-level partitioning of programs. However, the compiler is still being written and I was unable to execute any code using it. Funding that has been explicitly targeted for this project is ending in 6 months. Although the SIGMA-1 represents the largest dataflow machine to date, the overall results of this project are disappointing due to a complete lack of usable software.

The second effort in the ETL dataflow group is led by Dr. Sakai. The goals of this section are: (1) the construction of a hybrid dataflow single-chip processor, (2) the development of an 80-processor prototype system consisting of these single-chip processors, and (3) the construction of a full 1,000-processor machine. So far, they have designed the single-chip processor and have manufactured five chips. The five chips along with 1 megaword of memory for each processor reside on a single board. The CMOS chips have 50,000 gates each and are being manufactured by the Japanese division of LSI Logic, which has a plant in Tsukuba. While there, I saw a demonstration of a Fibonacci algorithm handed-coded in assembly language execute on the five processors.

The EM-4 section believes that "pure" operational dataflow is inefficient and has, therefore, built the processor with a hybrid dataflow model called the "strongly connected block model." The main feature of the model is to take an instruction level dataflow graph and to collect nodes together into many single "strongly connected blocks." Each strongly connected block will then be executed on a single processor von Neumann style with a

program counter and registers. Anything outside of a block will be executed in a dataflow model where matching operands fire an instruction. Strongly connected blocks are macro nodes in a dataflow graph and execute when all of their operands arrive. The model incorporates the ability to execute variable size dataflow nodes from a single instruction to an entire program.

The multiprocessor machine has an Omega interconnection network where each node of the network is a processor-memory pair. One of the more unique features of the system is a built-in hardware capability to collect processor activity. A token is circulated around the network that collects activity information about the amount of allocated heap storage and the amount of unmatched tokens for the least active node. Load balancing mechanisms can then use this information.

There seem to be two major weaknesses in the effort currently. The first is that no floating point hardware is incorporated on the single processor chip. The machine was funded as a symbolic processor, not as a numeric processor. The designers view this aspect of the project as politically motivated to ensure uniqueness compared to the SIGMA-1 machine. The second weakness of the effort is the same problem that the SIGMA-1 effort had—all hardware, no software. Only time will tell whether the software will come. The plan seems to be to use whatever the SIGMA-1 project had in terms of software, but it is not currently usable.

The third section in the ETL dataflow group is designing a coarse grain dataflow machine called CODA. Because of language difficulties, I understood little of what was unique about this project. The effort is based around multi-threaded architectural ideas and is early in its design stages. Concepts have not been finalized and no hardware has been built.

SONY COMPUTER SCIENCE LABORATORY

David K. Kahaner

An overview of Sony's Computer Science Laboratory (CSL) is given. CSL specializes in research on object-oriented programming and distributed operating systems.

INTRODUCTION

In addition to TVs, Walkman, Diskman, and other widely known consumer electronics, Sony also has an active computer division and sells a well-regarded workstation (Sony NEWS). The Workstation Division is essentially a development arm. Sony also supports the Sony Computer Science Laboratory (CSL) with quite a different mission. CSL is "devoted solely to research. [The] job does not encompass development and production... [and] will be involved in a more complete range of basic computer studies."

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Sony's CSL is located in the Shinagawa area of Tokyo. This is inside the "loop" line of the Yamanote subway and thus essentially in central Tokyo. CSL occupies one floor of a new building around which many other Sony buildings are scattered like buckshot. The office facilities are airy, spacious, and modern, with about a dozen computer scientist researchers working in outside-facing offices with ample large windows surrounding a central core containing meeting rooms, secretaries, etc. The model for CSL is taken from the United States, and here it has been carried further than in many other places. For example, there are no signs indicating titles or seniority. As might be expected, there are large numbers of computers, workstations, VCRs, and associated equipment in attendance. In fact, given the number of researchers, this is one of the nicest looking research facilities of its type I have seen in Japan.

Organizationally, CSL is an entity separate from Sony Corporation, but of course it gets all its funding from Sony. CSL is about 2 years old, its birth being more or less coincident with its director's move from Keio University, where he still spends 1 day a week. Several of the other CSL staff obtained M.S. or Ph.D. degrees from Keio as well, and the university is an important source of student assistants. Western visitors to the Computer Science Department at Keio, such as Professor Carl Hewitt of the Massachusetts Institute of Technology, also collaborate with CSL's research staff.

SONY NEWS

Sony's NEWS workstation has some features that make it particularly attractive to the non-English speaking world. These center around the use of a 2-byte representation for text characters. On "traditional ASCII" computers such as an IBM PC, 1 byte (8 bits) is associated with each character; this permits 2**8=256 possible characters. The ASCII representation defines the characters associated with half of these bit combinations. The remaining combinations are undefined and vendors are free to use them for their own purposes, which they do. The 128 defined characters are more than enough to represent all the English letters in upper and lower case, digits, and punctuation signs, even while leaving some space for special characters such as the one that generates a "beep." In practice the byte value of a character is a pointer into a "font" table (often encoded in hardware); asking for the character with byte value 66 (decimal) = 01000010 (binary) causes an association with the 66th character in the font table--in this case a capital B. Vendors can introduce special characters by using the 128 byte values not defined by the ASCII code such as IBM does for some Greek symbols. These are sometimes called the "high order bit characters." By redefining the font table many other character sets are also possible. Fonts are usually built-in via hardware and these are the easiest to use, although software fonts are also common.

The 1-byte representation works nicely as long as fewer than 256 characters are needed in a font. But for character sets such as Japanese, 1 byte is not really enough. It is possible to get around the problems to some extent, as Sun and others do, via software. A software approach is okay for text inside files, but by using 1 byte it is more complicated to encode names of files and, subsequently, use them in a natural way. In any case the Japanese computer vendors use a 2-byte representation. The major disadvantage of all 2-byte representations is that fonts require more memory. Although this was serious in the past it is much less so now. There are at least two distinct 2-byte encodings in use. The oldest allows a character sequence to be in 1-byte ASCII form until a special "shift in" character is encountered. After that each character is represented by 2 bytes until a "shift out" character is seen, at which time succeeding characters are again in 1-byte form. This way the 2-byte sequence can represent 2**16=65536 possible characters. A second encoding, and the one used by Sony, encodes characters in either 1- or 2-byte form as follows. ASCII characters are represented by 1 byte. Japanese characters are represented by 2 bytes, of which the first always has byte value larger than 128 and the second has byte value less than 128. A disadvantage of the first encoding is that by looking at a character it is not possible to tell immediately if it is Japanese or ASCII, and to check means scanning to the left (perhaps a long way) until eventually a "shift in" or "out" character is encountered. The second representation only requires looking at most one character to the left. Although Sony's approach can only store half as many characters, about 32,000, this is more than enough to include all the Japanese characters as well as those from many other alphabets such as German, Russian, etc.

Because of the ease with which 2-byte representations can accommodate non-English languages, they are popular in European countries as well as in Japan, China, etc. My own observations are that Japanese like to use Japanese on computers. Suggestions that most scientists use English, especially in writing programs, are false.

The original NEWS workstations were based on 68000 chip sets. Using MC68030, with 4 MB real memory without cache, is a common setup. In the newest versions Sony uses customized RISC (Reduced Instruction Set Chips) chips to enhance performance. Other workstation vendors such as Sun and IBM also use RISC architecture for the same reason. I was not able to visit the Workstation Division, but it is no secret that Sony is working on a multimedia product, capitalizing on their expertise in audio-visual technology.

Sony has also recently introduced a "palmtop" computer, about 8 inches square, weighing about 1 pound. This has no keyboard but instead uses an attached stylus that is used to drag windows around a screen much the way a mouse would on a Macintosh. With the stylus, users can also write characters that are then interpreted via a neural-network algorithm. This seems to work very well on even complicated Chinese kanji characters as long as they are stroked in the order that students learn them. It works less well for western letters, perhaps because there is more variability in the way we draw them, or perhaps because more effort was put into the Japanese side of the input scheme. There is no indication that this device will be exported from Japan. All the buttons have Japanese labels. In any case, in its present form it is obviously much better suited for information recall than information input. Although this is the first device using a stylus, there are a great many pocket-sized computers on sale that are designed for use as memo pads and to keep track of address and telephone numbers, airline and train schedules, etc. Almost all of these have plug-in modules containing data, such as local train information, language translation tables, and so forth. My expectation is that most of these will fail as commercial products, but that there will be some residual learning that will be beneficial on future products.

RESEARCH AT CSL

I spent most of my time at CSL with Ric Smoody, an American who has been there for about 2 years and will be returning to the States in early June. Smoody worked several years at Tektronix on Smalltalk applications and has been looking into the use of object-oriented application programs at CSL.

The researchers at CSL, like Smoody, are not particularly interested in numerical computation. In fact, when I asked Smoody about floating point on the Sony workstation, he explained that he really didn't know if there was an attached coprocessor or not, but that numerical computation seemed amply fast for his needs. CSL's current work falls into two large categories: building a distributed operating system and independent but related research in object-oriented programming. I am not an expert in either of these fields, but I will try to summarize my sense of their work based on readings and discussions.

An object is a physical or logical entity that is self-contained and provided with a unified communication protocol. This means that an object can communicate with any other object through the communication protocol when it knows the addresses (or IDs) of the object. An object possesses a set of procedures that corresponds to computable requests and a local storage to keep its state. An object can be viewed as a small computer that is dynamically created and destroyed and that has local storage for computation.

Object-oriented computing is a method of computing in which objects request computation and receive answers from each other in terms of the unified communication

protocol. In a more traditional computing model, computation proceeds by executing algorithms or procedures. In the object-oriented computing model, computation proceeds as mutual effects among objects. Object-oriented models of computation have provided capabilities for abstracting systems as collections of small, indivisible, computation entities. These interact with the rest of the system by means of passing messages. Such a model has been helpful in designing and modeling real systems. The main contribution of this view is that it separates the phenomenon, that is the way objects interact with the external world (their interface), from the way the objects are implemented, that is their inner structure.

Smalltalk, with which many readers will be familiar as a programming language, can be considered as an implementation of an object-oriented operating system. It incorporates the notion of object and inheritance of characteristics. It provides memory management and a scheduler. However, it lacks essential operating system features such as files, support for other programming languages, multiprocessing, and distributed computing.

The major research project at CSL is the Muse operating system. This is an object-oriented operating system that is specifically designed to deal with some of the problems inherent in Smalltalk as well as to extend its concepts. In particular, Muse should be appropriate for use in a world consisting of a large number of heterogeneous computers that operate more or less independent of each other and widely separated. The system is designed to provide services by which users can tap into network resources transparently, even though the resource is topographically far away, and by which programmers can readily construct distributed programs that can communicate with each other in real time.

This is a 5-year project in the following parts.

(1) Basic architecture design
(2) Prototype implementation on Sony NEWS workstation
(3) Evaluation of prototype and redesign
(4) Implementation of Muse based on redesign
(5) Distribution as public domain software

Currently, the project is in stages 2 to 3. Professor Richard Schlicting, from the Computer Science Department at the University of Arizona, who is on sabbatical at Keio University, commented to me that although Muse itself is not yet very well known in the mainstream distributed operating system community, Tokoro himself (CSL's director) is a regular conference attendee and reasonably well known.

GENERAL REMARKS

Research in distributed operating systems is going on at many outstanding universities and laboratories throughout the world. The Sony CSL group consists of the director, Dr. Tokoro, who has a very clear sense of where the project is going, and about a dozen other researchers, some of whom are not as experienced. For example, Tokoro is a coauthor on almost all of the CSL technical reports (see list below). Thus the direction is strongly influenced by his view as well as by collaborations and visits from other research projects. The group seems to be up to date on related activities in the field and is in no danger of "reinventing the wheel." The staff is well travelled and is encouraged to present papers and attend international meetings. Nevertheless, at the moment CSL does not resemble a university computer science department that is likely to have a collection of independent-minded researchers each going off in his/her own

direction. The applications development, such as Smoody's work, will only have one person after he returns to the United States, and thus is in danger of faltering. Sony Corporation has clearly stated that it will leave CSL alone to think long range, but this lack of parent organizational pressure also can have obvious disadvantages in lack of focus, although I have no indication that has happened.

CSL states that it wants to "participate in international joint research with laboratories operated on the same principles as ours." CSL is also interested in sabbatical or similar visits from computer scientists. Given its excellent facilities and open-minded view of research, this would be an outstanding opportunity for western scientists, particularly those who would like to work on object-oriented applications, or who have a project related to one of those that CSL has identified as important--distributed operating systems, programming languages, system architectures, or user interfaces. At this time there does not seem to be much overlap with research in numerical scientific computation, although distributed systems are clearly important in the world of parallel processing. In the long run, if CSL wants to bring "upper-echelon scientists from around the world ... [to] ... work together with pride and enthusiasm to achieve breakthroughs of universal value," its challenge will be to develop a collection of research projects whose genesis spans several talented individuals.

The following are recent CSL research reports.

(1) Yokote, T., Teraoka, F., and Tokoro, M., "Object Management in the Muse Operating System," Technical Report SCSL-88-001.

(2) Teraoka, F., Yokote, Y., and Tokoro, M., "Inter-Object Communication in the Muse Operating System," Technical Report SCSL-88-002.

(3) Yokote, Y., Teraoka, F., and Tokoro, M., "A Reflective Architecture for an Object-Oriented Distributed Operating System," Technical Report SCSL-89-001.

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U.S.-JAPAN WORKSHOP ON SMART/INTELLIGENT MATERIALS AND SYSTEMS

Iqbal Ahmad

This workshop was organized by the Army Research Office as a follow-on of its first workshop held in September 1988 at Virginia Polytechnic Institute (VPI). The objectives of this second workshop were to clarify the basic concepts of smart/intelligent materials and systems and reach some consensus on the terminology to be used in the future, to develop some guiding principles for the design and fabrication of such materials and systems, and to discuss some of the ongoing research in various laboratories.

INTRODUCTION

The Army Research Office (ARO) organized the first workshop on smart materials, structures, and mathematical issues at VPI in September 1988 [see C.A. Rogers, E.S. Chen, and A.F. Findeis, "International Workshop on Intelligent Materials," *Scientific Information Bulletin* 14(3), 23-33 (1988)]. In April 1989, the Society of Non-Traditional Technology of Japan held an international workshop on intelligent materials. These workshops brought into focus the fact that while there has been considerable activity in the United States in the area of design and fabrication of so-called smart or intelligent structures, in Japan the emphasis has been more on the formulation of the concept of intelligent materials and systems. In other countries, the scientific community is also becoming aware of this new concept. Nevertheless, in spite of both the workshops, the concept has remained vague. As yet even the terminology, such as "smart," "intelligent," and "adaptive," is being used loosely and interchangeably. There is no consensus on the technical definitions of these terms. ARO, therefore, decided to organize this U.S.-Japan workshop in which active researchers in the field, not only from the United States and Japan but also from Europe, were invited.

The objectives of the workshop were to clarify the basic concepts of smart/intelligent materials and systems and reach some consensus on the terminology to be used in the future, to develop some guiding principles for the design and fabrication of such materials and systems, and to discuss some of the ongoing research in various laboratories.

The workshop consisted of five sessions: (1) Concepts-Plenary Session; (2) Smart/Intelligent Systems; (3) Smart/Intelligent Materials; (4) Control, Integration, and Math Modeling; and (5) ARO Program Overview and Panel Discussion. In addition, from each session two representatives were asked to identify and discuss important issues within the scope of the session and prepare a position paper for general discussion at the end of the meeting. This article summarizes the highlights of the materials presented and discussed during the various sessions.

CONCEPTS

During the last 2 years, the concept of smart/intelligent materials and systems has been described in many ways. At the 1988 ARO workshop, one of the proposed definitions was a system or a material that has built-in or intrinsic sensors, processors, control mechanisms, or actuators making it capable of sensing a stimulus, processing the information, and then responding in a predetermined manner and extent in a short/appropriate time and reverting to its original state as soon as the stimulus is removed. At a more advanced level such materials and systems could have the capability of self-diagnosis, self-repair or regeneration, forewarning, and life prediction.

At the workshop, Dr. Toshinori Takagi, in his opening speech, presented a concept that was based on the Japan Council for Aeronautics, Electronics, and Other Advanced Technologies report titled "The Concept of Intelligent Materials and the Guidelines on R&D Promotion," published in November 1989 by the Science and Technology Agency (STA) of Japan. According to this report, "intelligent materials may be defined as the materials which respond to environmental changes at the most optimum conditions and manifest their own functions according to the changes." Dr. Takagi explained that the concept is composed of three elements: intelligence from the human standpoint, intelligence inherent in materials, and primitive functions of intelligence. Every material has primitive functions because of the inherent properties emanating from its electronic and atomic structure. Until recently, such properties have been manipulated to develop various useful devices and adaptive systems from these materials. During the last two decades, dramatic advances in electronics and computer science have made possible the incorporation of software in systems, which gave them the capability of adapting to changing environments. New techniques for the design and fabrication of materials have enabled the synthesis of many novel classes of functional materials including semiconductors, magnetic materials, and superconducting oxides. The hybridization of such materials could lead to material systems with intrinsic mechanisms for sensing, control, and response, in other words, material systems with intrinsic intelligence (albeit at the lower end of the scale of intelligence).

The proposed goal of the Council for Aeronautics report is to promote research and development (R&D) to achieve material systems with higher intelligence levels and with the capability to recognize, discriminate, and adapt using advanced functional materials. The ultimate objective proposed in the report is to work towards material systems that can function "in greater harmony with the environments in which they are used." According to Dr. Takagi, material systems will progress in the future from the discrete to the hybrid to the fuzzy state.

Dr. Kiyoshi Takahashi, in his presentation on the concept of intelligent materials for electronics, defined intelligent materials as materials that possess characteristics close to those of living organisms. Until recently, major efforts in materials science and technology have been to achieve higher strength in naturally occurring materials. But the emphasis has shifted to developing the functional characteristics of these materials. This trend could lead to an increasing level of complexity in material systems. It is out of such complexity, according to Dr. Takahashi, that intelligent functions can be realized. Such materials can be designed at the atomic level. The process may be referred to as "genetic control in materials science." To accomplish this successfully, specific rules will have to be developed. They could be derived from established concepts

such as: (1) atoms with an even atomic number make insulators, while those with an odd number form conductors; and (2) the energy band structure within the solid is determined by the periodic potential for electrons. And there are others. By using superlattices and quantum effects, it may be possible to create minibands of energy levels. According to Dr. Takahashi, with such minibands, "forbidden" bands that are so important to electronic devices could be freely controlled. When it becomes possible to freely design and create materials at the atomic level, it would then be possible to produce intelligent materials. At that stage, as it is in living cells, the integration of electronic, mechanical, and energy components will make it difficult to differentiate between the material systems and devices. They would have analog rather than digital functions, which is one of the characteristics of intelligent systems.

Prof. Craig Rogers presented "Concepts of Intelligent Mechanical Systems." He based his thoughts on a report titled "Research Needs in Dynamic Systems and Controls," published in 1988 with National Science Foundation support. He stated that in the United States the R&D efforts of the scientific community have centered around the control of mechanical systems. This trend was obvious from the U.S. presentations at this workshop. He reviewed the ongoing work related to the control of vibrations in composite structures using shape memory alloys, electrorheological (ER) fluids, and optical fibers and the processing of such composite systems for use in civil engineering applications. Prof. Rogers did not advocate any particular definition or terminology and concentrated on the goals and challenges of intelligent systems. He is the chief editor of the newly instituted *Journal of Intelligent Material Systems and Structures.*

Intelligent biosystems were discussed by Prof. Mauricio Montal and Prof. Masuo Aizawa. Prof. Montal described the functioning of channel proteins, which have ion channels (the actual polar pathways that permit the selective passage of ions across the apolar lipid bilayer) and a sensor (the structure that detects the stimulus and couples it with the gating of the channel). These two functional elements make these proteins intelligent materials. Prof. Montal described the progress made in his laboratory in the design and synthesis of peptides and proteins that emulate the pore structure of two prototype proteins of two major gene families in the brain, namely, the voltage sensitive sodium channel and the nicotinic cholinergic receptor. Prof. Aizawa suggested that intelligent materials may be simply "feature structural integration of sensing, information processing, and actuating capabilities. The concept of intelligent materials is to install software capability for coordinating such unit functions as sensing and actuating." He gave several examples of intelligent biomaterials, including a receptor molecular assembly embedded in a biomembrane. He discussed the concepts of an artificial pancreas, a calmodulin modulated protein assembly, and an electroconductive polymer-enzyme system in which the enzyme and the conducting polymer serve as effector and receptor, respectively. He also reported successful synthesis of a polypyrrole/glucose oxidase molecular assembly as a model of intelligent materials.

National Aeronautics and Space Administration (NASA) space missions have been the major motivation behind the design and development of smart/intelligent structures in the United States. Such missions require large precision structures, such as large deployable reflectors and optical interferometers, which are 20 to 100 meters, with a stable accuracy requirement of a few microns to submicrons. Because of their size, these structures must be deployed or erected in space. Other examples include large observational platforms with

solar energy panels, antennas, radiators, and multiple instruments to observe the Earth and its environments. For the success of these missions, these structures have to be adaptive. Terms such as "controlled structures," "smart structures," "intelligent structures," and "active structures" have been used in areas similar to the adaptive structures. Dr. Ben Wada reviewed them in an American Society of Metals (ASM) booklet. He defined adaptive as "those systems whose geometric and inherent structural characteristics can be automatically changed in space to meet the requirements in response to initial errors or external stimulations." Dr. Wada described some of the features of adaptive components integrated into precision truss structures, which are important parts of the structures proposed for erection in space. He reported successful use of active members involving piezoelectric actuators to statically adjust a truss structure. Also presented were the analytical results, which showed agreement between the predictions and the experimental results obtained at the Jet Propulsion Laboratory.

Prof. Richard James highlighted the optimization aspect of intelligent materials and structures. With biomaterials, we rely on the hope that nature has already performed the optimization through the process of evolution. But the optimization criteria in man-made systems are often incompletely understood and are multifaceted. The conventional approach to optimization of a material has been to treat a case in which a number of possible arbitrary microstructures compete for the minimum (or a maximum). He explained in simpler terms recent advances in the mathematical techniques and their use in the optimal design of materials, particularly phase transformation in active materials such as shape memory alloys and magnetostrictive materials.

INTELLIGENT SYSTEMS

In the session on intelligent systems, a number of structures for space as well as concepts of health monitoring of future aircraft and micromachining were discussed. Prof. Koryo Miura, reviewing the progress of research on adaptive structures in Japan, stated that he had proposed the concept of variable geometry truss at the 1984 International Aeronautical Federation in Laussane, and in 1985 he had reported a variable geometry truss operated by a personal computer and demonstrated for the first time the potential of the adaptive structure concept. Since then rapid progress has been made in this field, and Prof. Miura reviewed a number of concepts including a two-dimensional deployable truss, construction of a structure in space, and a large deployable antenna reflector having shape control capability. Mr. Garnet Horner discussed ongoing research on adaptive structures at NASA Langley and reported results of vibration control experiments.

The Air Force has the most stringent set of design requirements for insuring the integrity of the aircraft structure. The current practice is based on damage tolerant design philosophy for flight critical structures. Complementing this approach is the USAF Structural Integrity Program, which is designed not only to track the actual usage of an aircraft but also to monitor the health of an aircraft throughout its service life. Mr. Tony Gerardi described the goals of this program, which ultimately seeks to emulate the human nervous system by using artificial intelligence and neural networking. He stated that the "Smart Plane" would not only monitor health but would also provide the pilot with real time mission essential information and the ability to make in-flight emergency decisions to override pilot commands or even make in-flight repairs to battle damaged structures.

In an interesting paper on intelligent micromotion systems by Hiroyuki Fujita, presented by Dr. Masaki Esashi, the concept of micromechatronics was introduced. Successful fabrication of micromotors of less than 100 microns, using micromachining techniques, was reported. These microsystems are made of silicon, silica, silicon nitride, polyimide, and some metals. Future goals of the ongoing research include the development of an integrated micromotion system that is composed of micromechanical elements, actuators, and logic circuits. Photofabrication processes were suggested as possible approaches to micromachining elements, the integration of which can produce complex autonomous distributed systems.

INTELLIGENT/SMART MATERIALS

Although a number of examples of intrinsically smart/intelligent materials can be identified in naturally occurring biosystems, the development of nonnatural synthetic smart/intelligent materials is still at the conceptual stage. Prof. Takahashi, in addition to presenting his view on the concept of intelligent materials as discussed above, also suggested possible approaches to achieving intelligence in synthetic materials. He highlighted the concept of complexity, which could provide, as it does in the biosystems, that additional property, which could be anywhere on the zero to one scale of intelligence. Prof. Takahashi alluded to some views of Prof. Paul Davis* that state that beyond a certain degree of complexity, a system develops characteristics that cannot be directly deduced from the primitive properties of the constituents but have to be determined by additional laws, which as yet have to be discovered. These characteristics as seen in the biosystems include intelligence, biomorphism, regeneration, and reproduction.

Prof. Paul Calvert explained some of the unique features of biological materials. For example, all biological materials are composites and are not monolithic in nature. They are open systems and they operate under conditions where material is being continuously laid down and removed, thus requiring a continuous supply of energy to maintain stability against a free energy gradient. Biological materials are made from a very limited number of molecular structures, and they form in aqueous environments at nearly room temperature involving good flexible manufacturing systems. Biological manufacturing philosophy and economics are quite different from the approaches used by conventional manufacturing science. He discussed some of his ongoing research in biomimetics in which the formation of ceramics and composites by growth of particles in polymer films and gels is being investigated.

Prof. J.F.V. Vincent described the structure of insect cuticle and identified some basic structural designs used by nature to achieve various mechanisms of energy absorption, including those leading to impact resistance, stiffness, extensibility, and surface hardening. Since the outside of the insect is covered with cuticle, all information reaching the insect from the outside world goes through this layer. To provide various functional capabilities, the cuticle has a variety of sensors, e.g., it has short hairs with tiny holes that can absorb chemicals, thereby giving the insect a sense of smell. Prof. Vincent recommended study and exploitation of some of the simpler mechanisms that nature has provided in such insects in the quest for synthetic intelligent materials and systems.

Biomolecules such as proteins, nucleic acids, and lipids assemble into a variety of cellular organella by self-organization processes.They play a key role in living cells. These assemblies are often called

*Paul Davis, *The Cosmic Blue Print* (Simon & Schuster, Inc., London, 1989), Chapter 10.

supramolecules. They can be regarded as typical examples of intelligent materials, as they have their own specific functions (such as transport of chemical substances, synthesis of biomolecules, or conversion of chemical energy to mechanical energy), they form by self-assembly processes, and they have the capability of transforming their structure in response to the changing environment.

Prof. H. Hotani discussed the mechanism of the flagellar motor action involved in the swimming of bacteria in liquid mediums. He also described "laser dark field microscopy," a new method by which rotation of a single flagellum can be observed and recorded. He reported that a single flagellum can rotate at a rate as high as 10,000 rpm at room temperature.

Hydrogel is a water-swollen soft material made of synthetic polymers. Prof. Y. Osada reported that these gels underwent shape changes by applying dc current, and the velocity of shape change was proportional to the charge density of the gel. He has developed a model of an electrically activated artificial muscle working in an aerobic and aqueous medium system based on the behavior of the gel. The muscle contracts and dilates reversibly by an electrical stimulus under isothermal conditions. Prof. Osada described other examples of such electroactive chemomechanical systems, including a permselective chemical valve and a drug delivery system.

Dr. T. Okano described the results of his studies on the use of thermosensitive polymers, such as a copolymer of N-isopropyl acryamide (IPAAm) with butyl methacrylate, as on/off switches in a drug delivery system.

An important approach to the synthesis of intelligent materials is to exploit the intrinsic property of certain molecules to form self-assembled structures. Prof. S. Miyata described new Langmuir-Blodgett (LB) film techniques developed in his laboratory that have the ability to control molecular assembly more precisely than that achieved by the ordinary method. He also reported an organic film laser, which consisted of a waveguide layer sandwiched between electroluminescent (EL) layers. The waveguide layer consists of LB molecules doped with Nd^{3+}, which shows nonlinear optical properties. When voltage is applied to the electroluminescent layers, a light is emitted from the Nd^{3+} ions as a result of excitation from the electroluminescence. The frequency of this emission is amplified because of the nonlinear optical effects in the LB films. Because of the cooperative phenomenon of EL and nonlinear optical effects, this system works as a visible laser.

Dr. Brian McLean discussed the modeling of a shape memory integrated actuator for vibration control of large space structures. A number of cases were analyzed for the shape memory actuators with and without biasing for passive responses at high and low temperatures, with and without wire prestrain, and with a closed loop temperature control algorithm.

INTEGRATION, CONTROL, AND MATH MODELING

To design and fabricate an intelligent material or system, it is necessary to integrate the sensor, actuator, and control mechanism in such a manner that they operate as a unit and meet the functional requirements for which the system has been designed. The session on control, integration, and modeling addressed some of the issues involved. The slewing control of a flexible structure, such as an aluminum beam with embedded piezoelectric sensors and actuators, presents a multiple input control problem. Prof. D. Innman discussed the equations of motion derived using a Hamiltonian approach. Improvement in vibration suppression was gained with a standard quadratic regulator control design.

Mr. Jerry Newsom, in his paper presented by Mr. Garnet Horner, described the NASA Controls-Structures-Interaction (CSI) Program and presented the results of some active vibration control experiments, which showed that embedded sensors and actuators were quite effective in controlling a large truss/reflector structure. He emphasized that proper modeling of actuators and electronic systems was as important as modeling the structure when employing active structure control and that there was a need for integrated structure/control design methodology, which presently is almost nonexistent.

Artificial neural networking (ANN) and its ability to model and control dynamical systems for smart structures were discussed by Prof. Michael Thursby, who is working on a new class of structures called "smart electromagnetic structures." These structures have integrated sensing elements (e.g., antennas), processing elements (neural networks), and control elements (PIN diodes), with the capability of adapting to external electromagnetic environments in real time. The inherent speed of ANNs, according to Prof. Thursby, can be used to provide real time processing power necessary in many smart materials and structures. One characteristic of intelligent behavior is recognition of impaired capability, so an intelligent system should be able to monitor its own performance and determine when one of its components has failed, causing it to lose one of its capabilities. This is especially important in autonomous systems.

Prof. Wallace Van der Velde reviewed the principal approaches for monitoring control systems for failure of their sensors and actuators. He then described experimental results of simulation studies performed at the Langley MINI-Mast and proposed that more reliable signatures of failure were produced when double sensor parity relations were introduced. Fault tolerant computers and software verification methodology are subjects of considerable significance and are currently being addressed by Prof. Van der Velde.

In recent years a number of powerful mathematical techniques have been developed that have applications in the modeling of new material structures and in the general area of nonlinear controls. Profs. K.H. Hoffman, Morton Gurtin, and Robert Kohn discussed these advances as applied to the modeling of shape memory alloys and the optimization of the design of material microstructures.

ARMY RESEARCH OFFICE UNIVERSITY RESEARCH INITIATIVE ON SMART MATERIALS AND STRUCTURES

The first workshop on smart materials, structures, and mathematical issues organized by ARO in 1988 generated considerable interest in the Department of Defense scientific community and led to the ARO-sponsored University Research Initiative titled "Smart Materials and Structures." In this program more than 20 projects have been initiated at various universities. They cover studies of sensor and actuator materials, control mechanisms, as well as engineering development of the so-called smart systems. Dr. A. Crowson, the manager of this multidisciplinary program, briefly summarized these projects in the last session.

CONCLUSIONS

From all the papers presented and the discussions throughout this workshop, including the position papers, the following conclusions can be drawn:

1. The concepts of smart/intelligent materials and systems remain amorphous. There is a complex hierarchy of intelligence in nature that varies from simple adaptive systems to anthropomorphic intelligence including thought processes, leading to new knowledge and its application to creativity and the capability of not only mimicking but exceeding nature in design and development of new systems. The main scope of the concept of smart/intelligent materials in the United States is limited to systems with integrated sensing/information processing and control/actuation with feedback mechanisms. Further implications include nonlinear controls, neural networking, fault detection/damage control, repair/residual life prediction, etc. Most of these concepts are utilitarian in nature. Such systems are being developed successfully and brought into service. The concepts as presented by Japanese groups are predominantly philosophic. In their concept the ultimate goal is to create anthropomorphic intelligence in the material systems, even the quality of harmony with nature. Research activities in the actual development of materials and systems have not begun yet. Hopefully, the recommendationsof the Council for Aeronautics, Electronics, and Other Advanced Technologies will generate an STA-funded program in the near future.

2. There was no consensus on the terminology to be used, although the trend appeared to be towards accepting the term "intelligent," with qualification. There is a strong need for developing terminology for various levels of intelligence. Presently, other than the biosystems, there is no convincing example of a man-made "intelligent" material. Many researchers have used the term "smart and intelligent" for sensor systems, actuator systems, and even for some of the materials used. For example, ER fluids, shape memory alloys, thermistors, and piezoelectric materials have been called "smart" or "intelligent." This obviously is not correct. ER fluids or shape memory alloys are not intelligent, as they need a sensor and control mechanism to respond in a useful (or an intelligent) way.

3. Progress in the design and development of "intelligent" systems including structures has been user driven. Numerous space autonomous structures with capabilities of self-damping and precise attitude and position controls have been designed and deployed. Large programs relating to health monitoring of dynamic structures, process control, and damage detection/control/life prediction are in effect in the United States. There is a need for superior sensors and actuators with fast response time, good thermal and environmental stability, and a high degree of reliability. Also, as Dr. Newsom pointed out, integrated structure/control design methodology with embedded sensors and actuators is nonexistent and calls for a well coordinated interdisciplinary program. Such a program should also include development of new techniques for optimization of the systems.

4. Most of the work discussed in the workshop relating to material systems was on the mechanisms of biosystems and biomolecules. Again the driving force is user need, as in the medical sciences (prosthetics, drug delivery systems, substitutes, etc.). These mechanistic studies are a very important source of new ideas and approaches to developing novel materials and systems with various degrees of intelligence. Prof. Montal's work on the molecular engineering of channel proteins and Dr. Vincent's research on the architectural design of insect cuticle are the types of studies needed. In fact, there is considerable strength to the point that instead of taking a leap-frog approach to understanding the functioning of the human brain for the purpose of designing synthetic intelligent systems and materials, it would be logical to study nature's simpler

intelligent systems both in the plant and animal kingdoms. There is a treasure of new knowledge in these biosystems that can be directly applied by both structural engineers and material scientists. It was also an expressed opinion of the majority that the work on the mechanisms involved in biosystems and on biomimetics must be brought to the attention of the engineers and material scientists, particularly the younger generation. The latter could be accomplished by including some of the basic information in textbooks at the undergraduate level.

5. Most of the currently designed intelligent systems are based on linear relationships. Greater emphasis should be placed on research on nonlinear control theory and its application in the design of advanced intelligent structures and materials systems. *Ab initio* modeling of polyfunctional materials as well as the advancement of mathematical techniques of structural optimization are other areas of future research.

6. To make meaningful progress in this emerging science, the interdisciplinary approach and international collaboration were stressed by most of the attendees. Hopefully the next workshop will be 2 years from now. Both the European group and the Japanese group offered to host the workshop. In the meantime, it is hoped that there will be an international effort to promote communication, interaction, and collaboration among the researchers in the field.

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PERPENDICULAR MAGNETIC RECORDING MATERIALS

Earl Callen

This report reviews the status of anodic oxidation, cobalt-chromium, Co-CoO, Co-Ni-Re-P, and Ba-ferrite perpendicular magnetic recording. The report then discusses multilayer film heads.

INTRODUCTION

In magnetic recording the push is toward ever higher bit density. Even more than for alpha-numeric data handling, the burgeoning demand for graphics data storage requires very large capacity. "Portable" computers weighing 25 pounds are portable only by over-the-edge computer enthusiasts without a suitcase in the other hand. The new laptop computers weigh 5 pounds or less. "Palmtop" is coming. Space is at a premium.

To attain higher fidelity in audio and video recorders requires more bandwidth. In audio, manufacturers are shifting from analog to digital recording. Typically bandwidth is increased from 20 Khz to the megahertz range. More data. High definition television must have greater bandwidth and also will in all likelihood go to digital processing.

Now factor in the enormous push [mostly a Japanese push, led by Nippon Telegraph and Telephone (NTT)] into x-ray lithography of 0.25 micrometer wavelength (and moving on to 0.2, 0.15, ... micron) of ultrahigh density DRAMS and ICs, energized by compact, industrial synchrotron radiation sources. Couple that with the market for portable video equipment and ever smaller, lighter, more portable microprocessor-controlled consumer electronics dispersed through the home, factory, office, transportation, communications, the military. There is compound impetus for high density memory storage.

Figure 1 (kindly provided by W.D. Doyle of Eastman Kodak Diversified Technologies Group) makes the point. Memory storage density has been going up exponentially for 30 years. Besides by somehow just staying on the longitudinal recording trend line of Figure 1 (a theme that will haunt this article), we are on the edge of a number of promising ways to get there, two of which are magnetic: perpendicular recording and magneto-optics. For example, the 1982 NTT JS4380 had a linear bit density of 14 KBPI (kilobits per inch) and a track density of 1,100 TPI (tracks per inch), which multiplies to an areal density of 15 MB/in^2, or a little less than 25 KB/mm^2. Perpendicular recording is capable of packing 100 KBPI--680 has been reported--and 2,000 TPI, an areal density of 200 MB/in^2, more than 300 KB/mm^2, 12 times that of the NTT JS4380. And magneto-optics promises 675 MB/in^2, 1 MB/mm^2, 45 times that of the NTT JS4380. (To place this on Figure 1, $\log_{10}$ of 675 = 2.83. But when?) Bell (Ref 1) compares magnetic and magneto-optical recording.

MEMORY STORAGE DENSITY

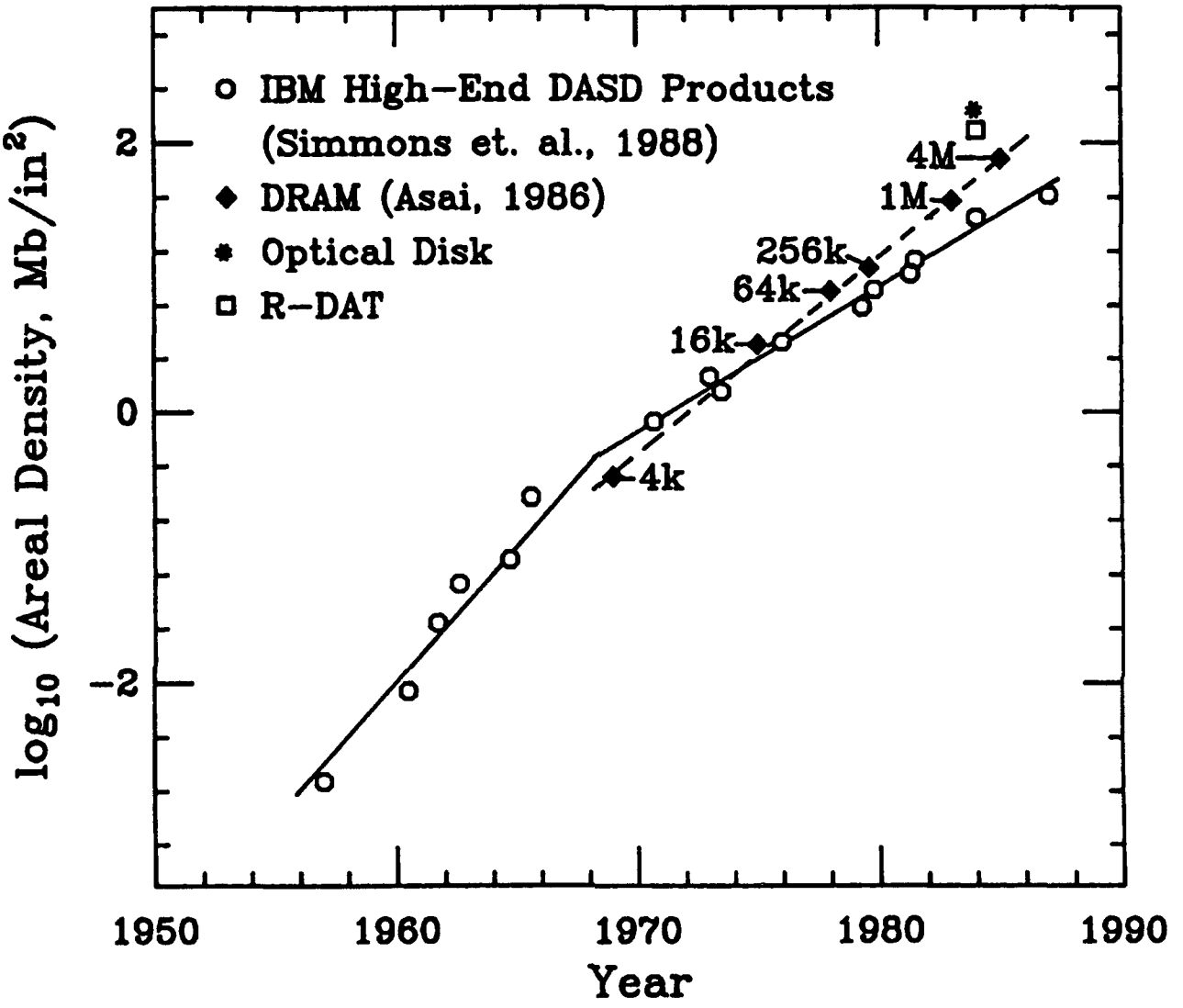

Figure 1. Exponential growth of memory storage density. The figure shows the log of the areal density plotted versus time, since 1950. Figure courtesy of Dr. Wm. Doyle of Eastman Kodak Diversified Technologies Group.

This article is about Japanese research on materials for perpendicular recording. It is not about magneto-optics or longitudinal recording, but comparisons will be made. The report is based on visits to Fujitsu, Hitachi Central Research Laboratories, Nippon Electric Company (NEC) Central Research Laboratory, Nippon Telegraph and Telephone (NTT), Toshiba, Tokyo Institute of Technology (Professor M. Naoe), and Yamaha. That the focus of this article is on Japanese accomplishments should not be taken to imply that the author believes that Japanese work is alone worthy of review, but rather that the purpose of this Far East Office is to report on what is happening here.

The author is pleased to have the opportunity to thank his hosts at those companies and many more. There is a view widely held in the United States that Japanese companies are secretive, their laboratories closed, difficult to penetrate. Visiting Americans often ask how we are able to function here without access to Japanese laboratories. This view is at variance with my 3 years of experience. Access is, of course, untrammeled at government laboratories and at the universities, except for the occasional problem of noncooperation with military. Japanese universities officially and often in practice exclude Japanese Self-Defense Force scientists as well as military employees of foreign governments. Some schools--Kyoto, Nagoya, Tokyo University--are more ideological than others--Tokyo Institute of Technology (where Self-Defense Force employees are even officially enrolled in courses, and where I have had invaluable use privileges of the library). With two exceptions I have found Japanese industrial laboratories at least as responsive and forthoming as their American counterparts. And, invariably, they are gracious hosts.

MAGNETIC RECORDING REFERENCES

There are a number of excellent books on magnetic recording (Ref 2-5), a 1986 IEEE publication of review articles (Ref 6), and a Japanese conference proceeding on perpendicular magnetic recording (Ref 7). [Those who wish to follow up on magneto-optics are referred to Japanese conference proceedings on optical memory and magneto-optics (Ref 8 and 9). Magneto-optical recording is reviewed by Bloomberg and Connell (Ref 10), by Meiklejohn in the IEEE series (Ref 11), and in two earlier articles (Ref 12 and 13).]

MAGNETIC RECORDING: Longitudinal and Perpendicular

In the earliest patented magnetic recording system, in 1898, the recording medium was a carbon steel wire (Ref 14). A 1930 tape recorder used paper strips coated with carbonyl iron particles as its recording medium. Today disks and tapes are used rather than paper strips or wires, but the principle is the same. The directions of magnetization of small regions of uniform magnetization--magnetic domains--in a ferromagnetic or ferrimagnetic film on the surface of a disk are oriented by a small electromagnet in a recording head that passes close to the disk. A rigid disk is spun at 3,000 to 5,000 rpm and the head is shifted radially (floppy disks are typically spun at 300 rpm). Domain moments along the track are bistable and, in overwriting, can be switched or maintained in either of two senses by running the current in either direction through the head coil. When a reading head (which may be the same R/W head) passes over the domain, the flux cut by the coil induces a voltage proportional to the time rate of change of the intercepted flux. (It is also possible to measure the flux rather than its time rate of change.) By signal processing the original recording signal can be retrieved. In some systems, before writing new information on a previously used disk, the stored pattern is first erased, either by the field of an erase head or by subjecting the whole disk to a sufficiently strong 60-cycle field.

In longitudinal recording the magnetization lies in the plane of the disk. To attain higher density the magnetization can be aligned perpendicular to the film plane. This increases the magnetic flux outside the film. In point of fact, since the magnetic field has no divergence and the energy is lower when the flux is in the high permeability

medium, the magnetic field pattern is vectorial in both perpendicular and longitudinal recording, with complex arrangements of flux around and between domains--what Iwasaki termed the "rotary magnetization mode" in longitudinally magnetized media. It was his observation of the rotary magnetization mode by Bitter patterns, and his recognition that a cause of signal distortion and reduction is rotation of the continuous vector magnetization field, that led Iwasaki to perpendicular recording (Ref 15 and 16). At low bit densities, demagnetization effects favor longitudinal recording because demagnetization fields tend to rotate domain magnetizations into the film plane. But as the density is increased, in perpendicular geometry the flux closes on itself in adjacent oppositely aligned domains and the effect of demagnetization becomes less important. At very high densities of perpendicularly magnetized domains there is no demagnetizing torque in the midplane of the magnetic material and at the film surface the torque is the same as with longitudinal magnetization. Thus magnetostatics no longer favors longitudinal recording as recording density is increased. We shall see an example of this in the discussion of Co-O.

Typically the recording head in longitudinal recording is the ring head, a high permeability "ring" with a gap. An imaginary line between the two magnet poles of the ring head would be parallel to and just above the film surface and would move along parallel to the film track as the disk rotates. Only the fringing field of the head penetrates the film. In the region beneath the poles the major component of the field of the magnet is parallel to the surface, thus being more favorable for longitudinal geometry. (But if the field is strong compared to the demagnetization and anisotropy fields, the perpendicular component--the larger component at the trailing edge--can be determinative.)

On the other hand, the single pole head is (at least theoretically, and with a double layer medium) favorable for perpendicular recording. In perpendicular geometry the film is effectively in a gap between pole pieces. The head holds the pole face of the main pole close to the film. Another pole, the auxiliary pole, is on the substrate side of the film, or this pole may be a layer in the film below the memory. Arrangements are different, of course, for rigid disks, floppy disks, and tapes. The head may be main pole-driven or auxiliary pole-driven. In any event the geometry is opposite to that of the ring head; the field directly below the single pole head is normal to the film plane and the field at the trailing edge is longitudinal.

For perpendicular recording, especially on tapes and floppy disks on which a slider holds the head in near contact with the protective layer or magnetic medium, within less than 0.05 micron of the surface, practical considerations and optimization may well tilt the balance in favor of the ring head (and single layer media), in spite of geometric considerations to the contrary.

But for use with rigid disks, where head-to-medium separation is a serious problem, the single pole head (and double layer medium) is frequently favored. The requirements for the magnetic sensitivity of the single pole head are demanding. We shall discuss efforts to create thermally stable multilayer films of high saturation magnetization and high relative permeability.

With rigid disks, in both longitudinal and perpendicular recording, to maximize c/n the recording (and/or reading) head is run at a flying height of a few tenths of a micrometer because signal (divided by

wavelength) drops off exponentially with distance between head and magnetized medium. Spacing is usually the most important source of loss, and at high linear bit density this is aggravated by the exponential dependence on inverse wavelength. A fleck of dust can cause a head crash. Because aerodynamic forces between the head and a smooth surface cause the head to stick to the disk, disks are roughened by scoring with emery tape. Flying height must be set high enough to avoid head bumps with high peaks (Ref 17), but at a cost in signal. Altogether, the mechanical tolerances are too close for comfort. As severe as these demands are, the trend, particularly in perpendicular recording, is toward lower flying height, since *the advantage of perpendicular recording is realized only at extremely small head-to-medium spacing.* The incredible goal--and close to attainment--is a flying height of a few hundredths of a micrometer--a hundred atoms!

Figure 2 shows why. The figure (Ref 18, courtesy of Hitachi) compares recording density D50 (linear density at which the output falls 50 percent) of longitudinal and perpendicular recording. The perpendicular recording experimental data, the dashed line, are from Yamamoto et al. of Tohoku University (Ref 19) and Shiiki et al. of Hitachi (Ref 20). In perpendicular recording, recording density D50 rises very fast with decreasing spacing. That conclusion is firm, independent of the particular medium or type of writing or reading head.

The solid lines represent simulated response for longitudinal recording for a thin film head and sputtered medium and for two values of a significant parameter (the transition length). Perpendicular recording measurements shown in the figure were obtained with a single pole head and double layer medium. For a head-to-medium spacing in excess of 0.1 micrometer longitudinal recording is superior, and below 0.1 micron perpendicular recording excels. But the reader should be wary not to conclude more than the authors of Figure 2 claim. With the magnetic head it may well be impossible to exceed 70 or 80 kFCI (kilo flux changes per inch) in longitudinal recording. But as we shall see, that density has already been surpassed with different technology.

Comparing one disk to another, or one tape to another, the significant measure of density is areal density. But in those situations that lend themselves to tape, such as high volume external memory, an appropriate consideration is bits per unit volume, since tape can be compactly stored. Magnetic tapes are now used in a streaming mode for rapid transfer of disk file contents to tape for archival purposes. The greatest future in high density recording is probably in tape more than in disks. Toshiba estimates that the market for audio and video tape is 10 times that for floppy and rigid disks together.

Magnetic recording linear densities continue to improve as the physics of bit interaction, magnetization distribution, and rotation becomes better understood. In a Co-Cr double layer medium, with a single pole head and a gap width of 0.3 micron, a spacing along the track of less than 50 nm--20,000 flux reversals/mm--can (in the laboratory) be recorded and reproduced (Ref 21 and 22). Track density is a challenge. In the Introduction we cite 2,000 TPI for perpendicular recording. (This is on a rigid disk. In a floppy disk environment tracking is more difficult. Toshiba's 16 MB Ba ferrite floppy disk has a track density of 542 TPI.)

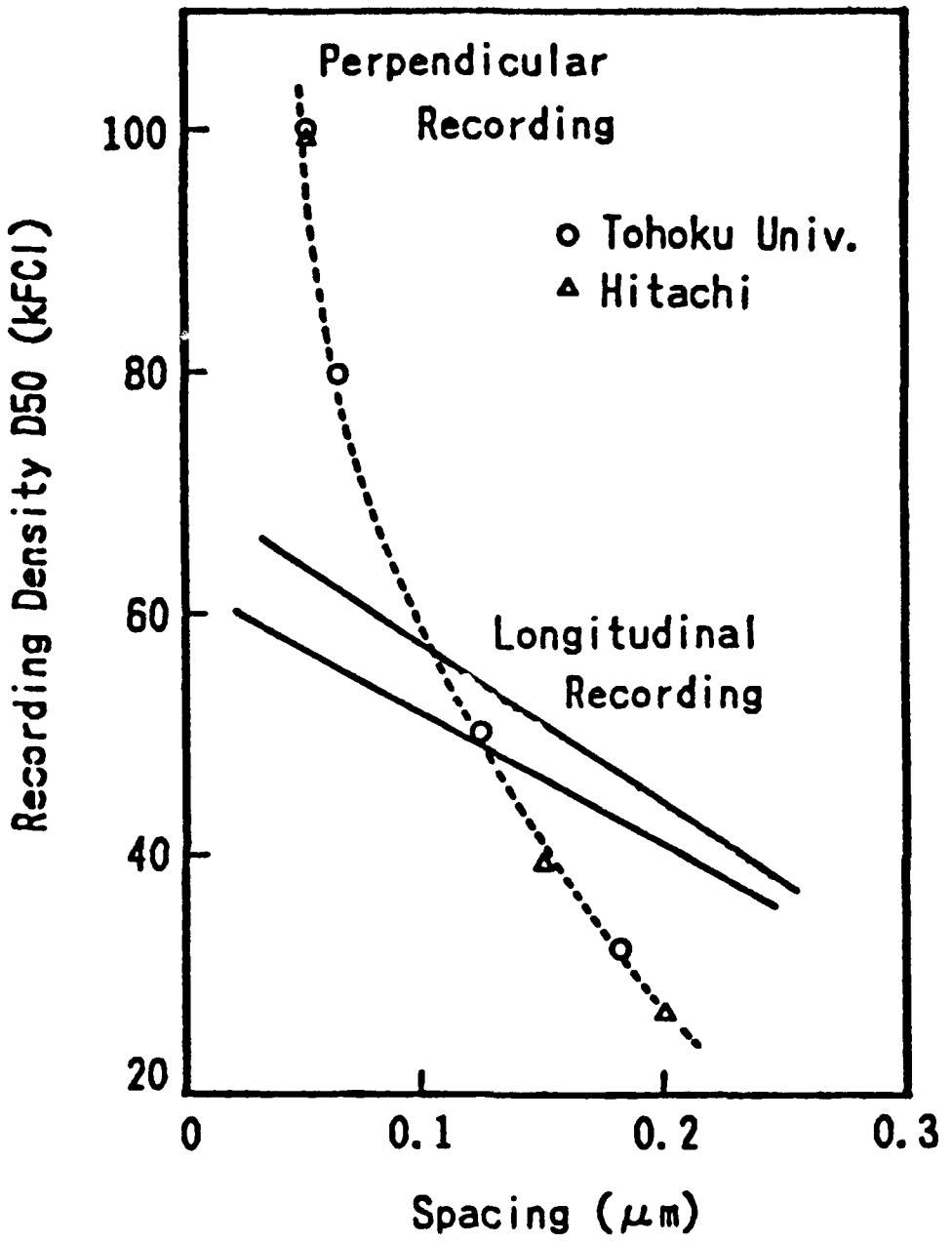

Figure 2. Comparison of longitudinal and perpendicular recording with respect to spacing. Figure courtesy of Hitachi Corp. (from Ref 18).

Perpendicular Recording by Anodic Oxidation and Pore Filling

At one point in his initiation this writer was enthralled by the Yamaha process for producing perpendicular magnetic recording rigid disks by anodic oxidation of alumina onto the aluminum disk, etching and enlarging pores, and filling with a ferromagnetic metal--iron (Ref 23). Shape anisotropy is the mechanism for maintaining the magnetization of the needle-shaped cores normal to the disk surface. Densities of 10^8 pores/mm^2 are achieved, beyond individual differentiation with present-day reading and writing equipment. Fortapes, anodic

oxidation is inappropriate. And, of course, there are problems. But whether because of technical problems, narrowing market window, or the unceasing technical advance of longitudinal recording, the bottom line is that Yamaha has terminated work on perpendicular recording. Anodic oxidation and etching definitely are useful--the texturing of longitudinal recording disks (Ref 17). With encouragement from American users (including IBM, we are told) Yamaha is developing a process for large scale production (in California?) of anodically textured longitudinal recording rigid disk base blanks.

Perpendicular Magnetic Recording Materials: Cobalt-Chromium

The reason Yamaha embarked on the anodic oxidized, filled pore disk was the horizon effect in Co-Cr. For 15 years now Co-Cr, the designer material, has been about to be commercialized--next year. Meanwhile, magnetically inferior particulate barium ferrite has gone to market. Used with the conventional, well-developed head-medium interface, pure Co-Cr lacked the mechanical strength to withstand head crash and pass wear. It is not chemically inert. Furthermore, it proved difficult to develop a mass production fabrication process that turns out, in the large quantities required, uniformly good quality Co-Cr media at a competitive cost. Nevertheless, because its magnetic performance remains superior to that of all other contenders with better mechanical properties, Co-Cr remains the most researched material for perpendicular recording. At the first-ever Conference on Perpendicular Magnetic Recording* (Tokyo, 29-31 August 1989), half the papers on media were on Co-Cr, and a large fraction of those were on pass wear durability (Ref 7).**

Serendipity and high intelligence combined in the discovery of Co-Cr. With Curie point writing in mind, Iwasaki (Ref 24) was looking at Co-Cr for magneto-optical Curie point memory. He wanted to lower the laser power by reducing the Curie temperature. To do this he added more Cr to his sputtered film. To his surprise the hysteresis loop (observed longitudinally in the film plane, which he expected would be the magnetization direction) suddenly became extraordinarily narrow and the loop lost its squareness. At that time no one had ever seen a film with perpendicular magnetization. But Iwasaki recognized what he was seeing and confirmed it with measurements in the perpendicular direction. With his insight into the dynamics of magnetization rotation (Ref 15 and 16) he recognized the advantage of perpendicular recording and off he went in hot pursuit! The woes of tribology came later.

* The second Perpendicular Magnetic Recording (PMR) Conference, dedicated to ultra-high density magnetic recording, perpendicular and *longitudinal* (emphasis added), will be held in Iwate Prefecture, Japan, 8-11 October 1991. Program co-chairman is Prof. Masahiko Naoe, Department of Physical Electronics, Tokyo Institute of Technology, 2-12-1, O-okayama, Meguro-ku, Tokyo 152, Japan. The emphasis is added to make a point. The first PMR conference was on perpendicular recording only.

** Other nongermane, but not inconsequential, statistics: of the 342 attendees at this conference, less than 50 were westerners. One might chide that the overwhelmingly Japanese attendance merely reflects the Tokyo locale. But at the Topical Meeting on Optical Data Storage in Vancouver, Canada, 5-7 March 1990--mostly magneto-optics--there were 138 Japanese authors and coauthors (not all in attendance) and 61 contributors from all the rest of the world. Japan is becoming the "Magnetic Monopole."

We can understand this now. Magnetocrystalline anisotropy energy, of spin-orbit origin, is the difference in energy per unit volume when the magnetization is in the easy and in the hard directions--in Co-Cr the hexagonal axis and in the basal plane. An anisotropy field, H_a, can be defined as the effective field of magnetocrystalline origin tending to rotate the magnetization toward the easy direction. With M_s, the saturation magnetization (the moment per unit volume), E_K, the angle-dependent anisotropy energy density, and ∇_s^2, its two-dimensional surface curvature (Ref 25),

$$M_s \times H_a = 1/2\, \nabla_s^2 E_K \qquad (1)$$

The total energy, a minimum at equilibrium, contains both anisotropy energy and demagnetization energy. For the magnetization to lie stably normal to the film plane, the anisotropy field must exceed the demagnetization field, $4\pi M_s$. Iwasaki is not only very smart but lucky. There are not so many uniaxial ferromagnets. Only in some of those is the uniaxial axis easy (Co and barium ferrite are others), fewer still in which the process of forming the film just naturally arranges the easy axis accurately perpendicular to the film plane, as does the columnar structure of Co-Cr which evolves in sputtering. But even so, in Co-Cr of what was then "normal" composition the magnetization lies in the plane. Because of the degenerate ground state of the Co ion, Co-Cr has large crystal anisotropy and hence a large anisotropy field, but not large enough; the demagnetization field $4\pi M_s$ is larger (see Equation 2 below). But in adding Cr to reduce the Curie temperature, Iwasaki also reduced the saturation magnetization below H_a, and beyond that Cr concentration at which anisotropy energy overcomes magnetostatic energy, the magnetization rotates from longitudinal to vertical. A composition of about 20 percent Cr is now usual.

A major step forward was the discovery, again by Iwasaki (Ref 26), that the recording and reproducing behavior of the Co-Cr film is greatly improved when it is deposited on a soft magnetic underlayer such as Ni-Fe. In 1987, recording on a multilayer film and reading with a single pole head, Yamamoto (Ref 21) of the Iwasaki group reported recovering signal at 680 kFRPI (kilo flux reversals per inch), with a track width of 100 micrometers. This is 26.8 FR/micron, a bit spacing of 370 Å.

A thin film of Ti on the substrate seems to predispose a Ni-Fe layer to promote epitaxial growth of Co-Cr and a high degree of c-axis orientation. Fujitsu, sputtering onto glass disks, puts 0.02-micron-thick Ti layers both above and below a permalloy underlayer (Ref 27).

It was not always understood whether the efficacy of a soft magnetic underlayer was in promoting Co-Cr crystal epitaxy and orientation or in decreasing demagnetization. It can do both. A recent study (Ref 28) makes clear that the high permeability underlayer reduces the energy of flux closure at the lower surface, stabilizing the perpendicular mode. The wave form can be sharp and clean. But there are tradeoffs and most Japanese companies are far from giving up on very practical single layer films and ring heads. At NTT, with a single layer film and ring head, excellent wave forms are obtained and overwrite noise is less than 26 dB.

Other Co binaries--Co-V, Co-Mo, Co-W--have been looked at in hope of finding a harder alloy. That Co-Cr remains the most researched material shows that these efforts have not been successful. Co-Ru and Co-Rh have good mechanical properties but are expensive.

Additives to Co-Cr have succeeded in increasing its hardness. Zr improves wear resistance and magnetic characteristics. Small amounts of C greatly increase the coercive force and induce segregation of the Cr (Ref 29). Co-Cr films with W-C additive have good magnetic characteristics, show fine grain structure, much improved pass wear, and are chemically stable (Ref 30). Ta is particularly effective (Ref 31). Co-Cr is not only mechanically flaky, but it is attacked by atmospheric gases and its coercive force and magnetocrystalline anisotropy degrade. In sputtering in an Ar atmosphere, the Ar gas also lowers H_c and pass wear durability. But with about 2.5 at. % Ta additive, Co-Cr-Ta is unaffected by N_2 and water vapor, the atmospheric components that degrade the magnetic characteristics (Ref 32), and films sputtered in Ar show undiminished magnetic behavior (Ref 32) and excellent pass wear performance (Ref 33). The original fabrication method, rf sputtering, has a low deposition rate; a technique more suited to mass production is needed. Tapes especially require high production rate because they are sold in such large quantities. Of the four ways to create films--sputtering, evaporation, coating, and plating--two are competing here: sputtering and evaporation. Sputtering makes the best Co-Cr films. Co-Cr gets its large uniaxial anisotropy from magnetocrystalline origin, but it seems to be the high energy of the normally incident sputtered atoms that brings about a columnar structure with the easy axis accurately aligned normal to the film plane. An angular spread of less than 1° is attained. And so it was natural to look at alternative means of sputtering such as magnetron sputtering. Films of good magnetic characteristics are produced and deposition rates were increased by a factor of 10. Facing target sputtering can produce uniformly good quality multilayer films at a rate suitable for mass production (Ref 34-38), but as far as I have been able to discover it is not in use in Japan. NEC makes its Co-Cr films by magnetron sputtering and argues that production rate will be adequate and equal to that offered by facing target sputtering.

Early efforts at evaporation of Co-Cr films increased production rate by two orders of magnitude but produced magnetically inferior films. Now evaporation has been improved to the point where it holds bright promise (Ref 39). By continuous vacuum deposition at a rate of 100 nm/s, Co-Cr tapes can be produced as fast as can particle coated tapes (Ref 40). Multilayer Co-Cr/Ni-Fe/Ti tape (Ref 41) and disks (Ref 42) can be vacuum deposited at a rate satisfactory for mass production. Quality--uniformity of composition and c-axis alignment--is inferior to sputtered films but "good enough."

Electron gun evaporation is a fast process, but in evaporation the particles drift down and deposit like snow; there is no powerful force to orient them. The problem of getting narrow angular spread is aggravated in evaporation from a point source (where sputtering is from an area source). In evaporating onto tape the electron beam is swept back and forth across the targets. This reduces misorientation in the transverse direction, but as the tape rolls by the source the deposition angle rotates from the initial approach angle, perhaps 20° from the normal, to the final angle, maybe -6° from the normal, depending upon the geometry of the continuous roller coater (Ref 43). Yoshida et al. found that with a Ge underlayer and a 0.7-micron-thick Co-Cr film the c-axis angular spread was reduced to 5°, but heat treatment is necessary to obtain good coercivity (Ref 43). The Hitachi group has now shown that the Ge underlayer can be dispensed with. Co-Cr is evaporated directly onto polyimide tape and good (or rather, for most purposes realistically adequate)

crystallinity, c-axis alignment, and magnetic characteristics are obtained with heat treatment (Ref 44).

We have referred to the columnar structure of the sputtered films. It was early recognized, again by Iwasaki (Ref 45 and 46), that the extraordinarily small bit size in Co-Cr, comparable to crystallite diameter, is related to compositionally segregated microstructures. Compositionally homogeneous films, with a long spin-spin correlation length and coherent magnetization, would reverse magnetization by domain wall motion. Films with highly segregated structure, with ferromagnetic Co-rich regions and paramagnetic Cr-rich regions, reverse magnetization by rotation of the moment in each separate grain. Figure 3 is the phase diagram, based on that published by Ishida and Nishizawa (Ref 47) and Hasebe et al. (Ref 48) to explain the properties of the binary alloy. The idea is a ferromagnetically induced phase separation. Note that the gamma and epsilon regions are divided into paramagnetic and ferromagnetic regions by the Curie temperature line. This has been observed in other alloys, and it extends over a region on both sides of the magnetic ordering transition. The dotted area in Figure 3, a region of magnetically induced phase separation, is the composition range of perpendicular recording Co-Cr. The concept explains some once-mystifying experimental results, that the saturation magnetizations and Curie temperatures of Co-Cr sputtered and evaporated films are higher than those of bulk samples in the 15 to 30 at. % composition range. Figures 4 and 5, kindly given to us by Maeda and Takahashi (Ref 49), show their lovely transmission electron microscope (TEM) micrographs of rf sputtered 18 at. % Cr films and 22 at. % Cr films. Patterns appear only in segregated films. Chemical etching, preferentially dissolving Co-rich regions, creates an elegant striped "chrysanthemum" pattern in the 18 at. % film and a "core and ring" (sometimes called "frog egg") pattern in the 22 at. % film. Maeda and Takahashi summarize the conclusions of a number of authors as to the magnetic properties of the segregated structures. These have a higher saturation magnetization than do homogeneous bulk alloys of the same composition. Films have their largest perpendicular anisotropy when they are highly segregated. Thus magnetically induced segregation seems to underlie the set of properties of Co-Cr that make it almost uniquely (but not quite; see CoNiReP below) attractive as an ultra-high density recording medium. (It also suggests that it is sensitive to substrate temperature, annealing conditions, and subsequent thermal history.)

Sagoi and coworkers at Toshiba also start from the solubility limits of the Co-Cr phase diagram in explaining the anomalously large saturation magnetization of sputtered films (Ref 50). In a paper yet to appear (Ref 51) they investigate a number of additives and confirm the common conclusion (Ref 29-33) that Ta confers excellent properties on Co-Cr.

Head-medium interface on disks has long been the subject of intense international investigation. "Doryoku" (stick-to-itiveness) is paying off. On the conventional coated disk, hard alumina particles reinforce the pigment, but at the cost of spacing. For high density perpendicular recording, thin film disk media have highly polished, very flat surfaces. At the top surface a SiO_2, B, or C layer (about 200 Å) protects the Co-Cr. Ion beam sputtered C or B is best but more difficult to apply. At Hitachi Maxell they evaporate amorphous B. They find that the Co-Cr remains intact after 10^6 passes. But these highly polished films are not tough. Without lubrication they do not stand up

well to head friction. Thus the surface is coated with a thin layer of oil. Surprisingly, one application of lubricant remains effective for the lifetime of the disk. Now particle/fluid composite lubricants are used (Ref 52). NTT applies a melamine cyanurate (MCA) composite lubricant in which the 100-Å MCA, oil-coated particles slide over the protective layer and absorb shock (Ref 53).

Virtually every company has developed a low weight, gentle head and slider and a way to keep flying heights below 0.05 micron. The new "soft touch," negative pressure head sliders for disks are designed so that aerodynamics keeps the head from sticking, even to a smooth surface; no texturing is needed. Everyone reports that pass wear is "no longer a serious problem." Mitsubishi Electric is making a flying head slider of the new design (Ref 54). Conventionally the slider lands on the disk when the drive is turned off and sits there until relative motion raises it when the drive is reactivated. This causes wear. Kyushu Matsushita Electric Co. (Ref 55) and NEC (Ref 56) are experimenting with negative pressure sliders that automatically load and unloaded from the disk, tripped by flying speed. With noncontact start and stop operation between slider and disk, a thinner protective layer and a lower flying height will be possible.

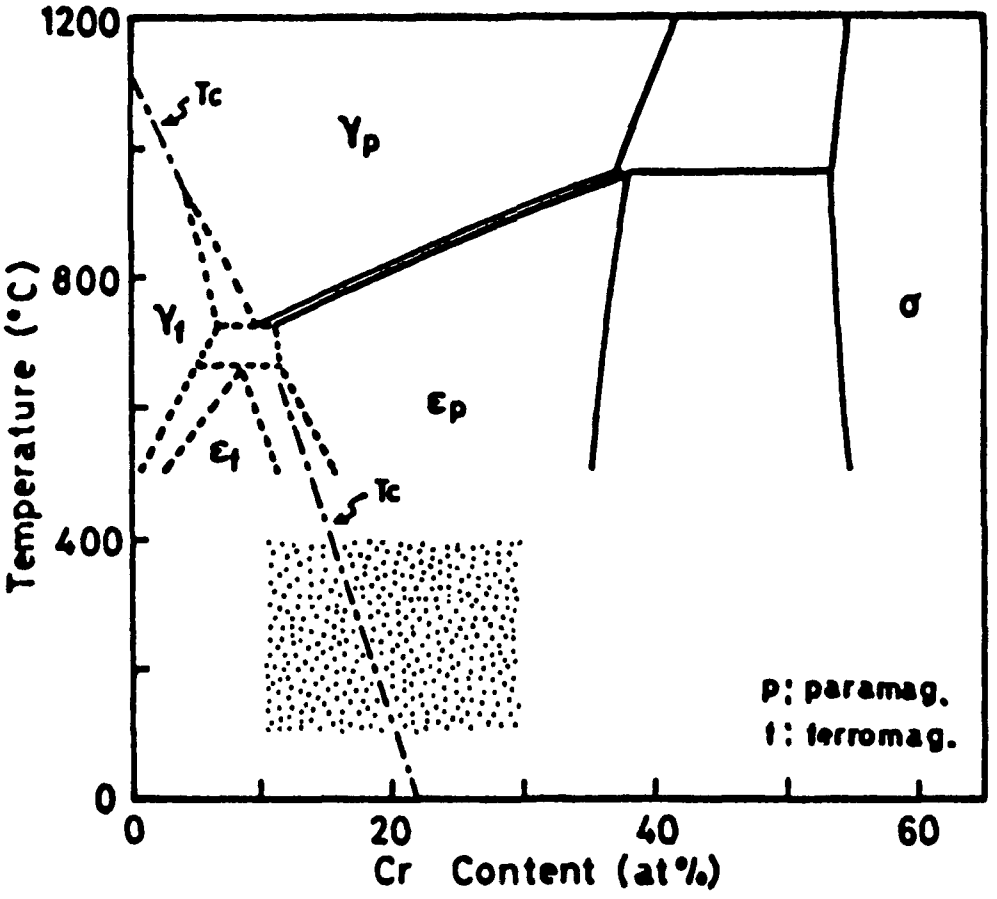

Figure 3. Cobalt-chromium equilibrium phase diagram, with Curie temperature line and region of magnetically induced segregation (adapted from Ref 48).

Figure 4. Chrysanthemum pattern in TEM of etched 18% Cr films. Courtesy of Y. Maeda and M. Takahashi (from Ref 49).

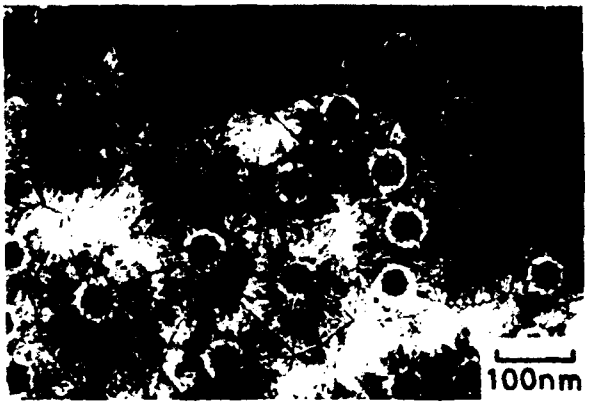

Figure 5. Frog egg pattern in TEM of etched 22% Cr films. Courtesy of Y. Maeda and M. Takahashi (from Ref 49).

Co-CoO Evaporated Films

Co-CoO, I think, illustrates a maxim of Lev Landau's, that applied physics can only be done by or in intimate cooperation with a user. (He was referring to military research and development and we are thinking of industry.) Co-CoO is magnetically inferior to Co-Cr. But it may compete with Co-Cr as a medium for perpendicular recording tapes and flexible disks and compete with Ba ferrite, discussed below. (Hitachi thinks so, but presumably Toshiba, which is heavily invested in Ba ferrite, is not worried. They are not working on CoO.) The reason is that for Co-Cr film prepared by vacuum evaporation to have good magnetic properties, the substrate temperature must exceed 200 °C. In Reference 44 the hot roller is at 265 °C and the film is improved by heat treatment at 400 °C. Polyimide film as the base film for flexible disks and magnetic tapes can withstand these temperatures but PET cannot; PET curls up and shrivels. (This is also a problem in sputtering; the base film gets hot.) But PET is cheap and polyimide is expensive. And so Co-CoO. Co-CoO can be evaporated onto tape and heat treated at lower temperatures than PET can tolerate (Ref 57-61).

Oka and Akamatsu et al. (Ref 62 and 63) have another way of preparing Co-O films at room temperature, and cheaply. They do so by reactive evaporation, at high production rate, with a supply gas whose composition is similar to air.

CoO illustrates another point made earlier--that the demagnetization effects that favor longitudinal recording at low bit densities are no longer effective at high bit densities. The coercivity, H_c, is proportional (proportionality constant C) to the difference between the magnetocrystalline anisotropy field and demagnetization field:

$$H_c = C[(2K/M_s) - N M_s] \qquad (2)$$

K, the lowest order anisotropy constant, is the coefficient of the l=2, $\cos^2\theta$ term in E_k, the angular-dependent anisotropy energy density of Equation 1. Both K and M_s, the saturation magnetization, are temperature dependent. N is the difference between demagnetization factors along the c and a axes (easy axis and in the basal plane, N_c-N_a). In Co-CoO the uniaxial anisotropy, with

easy c-axis again, would not be enough to overcome $4\pi M_s$ and align the magnetization perpendicular for an isolated domain or at low bit density. But at high density, with bit size comparable to film thickness, the demagnetization factors are more nearly equal and the magnetization lies perpendicular (Ref 60).

Tateno, Iwasaki, and others (Ref 64) show that the magnetic anisotropy of Co-O comes from the magnetocrystalline anisotropy of Co and the shape anisotropy of the Co particles. Columnar structure is not a significant contributor to the perpendicular magnetic anisotropy of the Co-O film. This is why Takayama and Yoshida (Ref 61) find the seemingly paradoxical result that with heat treatment the columnar structure disappears, perpendicular anisotropy *decreases*, Co grains grow, and crystallinity improves, and both signal output and recording density characteristics are markedly *improved*.

Co-Ni-Re-P

The attraction of Co-Ni-Re-P is that it can be electroless-plated (Ref 65-70), and electroless-plating is a cheap and reliable process well adapted to mass manufacturing. The films are deposited from plating baths onto Cu and NiP substrates. The magnetization is perpendicular to the film plane. At about 30 at. % Co the magnetocrystalline anisotropy is a maximum. There is tentative evidence that in this material, as in Co-Cr, compositional segregation creates Co-rich ferromagnetic regions isolated by paramagnet barriers, allowing in-grain moment rotation (Ref 68 and 69). T. Osaka, the discoverer and champion of electroless-plated Co-Ni-Re-P, has shown that a plated underlayer can enhance the perpendicular recording characteristics of Co-Ni-Re-P floppy disks (Ref 70). NEC has a group working on this medium. They, too, have produced floppy disks, with underlayer, magnetic medium, and overlayer all deposited by plating. Their work has so far been reported only in Japanese; it was presented at a special meeting on magnetic recording in May 1990.

Barium Ferrite

Barium ferrite, a magnetoplumbite hexagonal ferrite, provides higher recording density (although lower than Co-Cr) than do longitudinal recording media. Being an oxide, it is chemically stable and corrosion resistant. Conventional head-medium interface can be employed; the barium ferrite medium is mechanically durable. It can be fabricated in thin film form or as a particulate film produced by conventional coating methods (Ref 71 and 72). This report covers only particulate coated films. Ba ferrite forms in flat particles with the c-axis easy and perpendicular to the flat hexagonal crystal surface (see Figure 6). It can be used either in longitudinal or perpendicular recording. In fabricating a perpendicular recording film, a dc magnetic field normal to the medium plane orients the easy c-axis perpendicular while a binder fixes the pigment coating (Ref 71-74). In making longitudinal media the applied field is in the plane of the medium and the flat particles are tipped up on edge.

A problem of many iron-based particulate media is low coercivity. The opposite situation applies to Ba ferrite, which was introduced as a permanent magnet material. But Kubo et al. (Ref 71) of Toshiba showed that substitution of Co and Ti in the ferrite $BaFe_{12-2x}Co_xTi_xO_{19}$ reduces the coercive force without reducing the saturation magnetization. With Co and Ti additives alone the coercive force actually increases somewhat with increasing temperature. The temperature dependence of the coercivity can be found by differentiating K and M_s

with respect to temperature in Equation 2 above. Individual sublattice anisotropy contributions vary with temperature as the third power of the reduced magnetization at very low temperatures, falling to the second power in the small magnetization, high temperature range (where the temperature derivative of the coercivity must be negative), but the sum of contributions can and does have a complicated temperature dependence (Ref 25). One would prefer a medium with temperature independent characteristics. Kubo et al. (Ref 75) found that a small substitution of Sn for Ti reduces by half the temperature derivative of the coercivity.

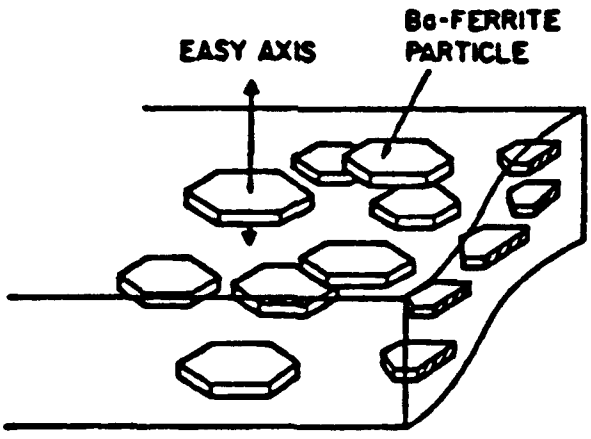

Figure 6. Flat, hexagonal Ba-ferrite particles. For perpendicular recording the particles are oriented with their hexagonal faces flat in the film plane. The easy magnetization axis is then normal to the film.

Again referring to the discussion surrounding Equation 2 above, for an isolated particle the net demagnetization factor N is purely geometric, depending upon ratio of particle radius to thickness, the aspect ratio. As might be expected, the larger the ratio (flat, tnin particles) the larger the demagnetization factor and the smaller the coercive force. But as particles are packed closer together they tend to pile up on top of each other, decreasing the aspect ratio and increasing the coercivity. The Toshiba Ba ferrite pigment has an aspect ratio greater than 3.

The development of a way to make, economically, commercial quantities of hexagonal ferrite particle pigment of small and uniform size, and of the right size and aspect ratio for the particular wavelength to be utilized, proved difficult. Small size is required for high recording density and high signal/noise. Conventional ceramic fabrication and many experimental methods were tried, but the best seems to be the glass crystallization method adapted by Kubo et al. (Ref 71) and Fujiwara et al. (Ref 72 and 73) from Shirk and Buessem (Ref 76). A mixture of BaO, B_2O_3, and Fe_2O_3, containing small amounts of CoO, TiO_2, and SnO_2 to adjust the coercivity, is melted and dropped between rotating steel nip rollers for rapid cooling to form amorphous glass flakes. The amorphous flakes are heat treated for crystallization. The crystallized Ba ferrite particles are separated from the flakes by dissolving out the remaining BaO and B_2O_3 compounds with an acetic acid solution. Strain free $BaFe_{12}O_{19}$ single domain fine particles of the desired size and shape and narrow size and shape distribution are produced. Average particle diameter is 530 Å and average particle thickness is 180 Å.

The particles have an interesting but troublesome surface effect (Ref 77). The saturation magnetization of the particles decreases linearly with increasing hexagonal face area, but almost not at all with side face area. Thus there is a low saturation magnetization layer equivalent to a thin 8-Å dead layer on the hexagonal faces. At low temperatures there is no magnetization reduction. This is explained, then, as not being a reduced moment effect but rather a thermal effect due to reduced exchange interaction (lower coordination number) of surface atoms

compared to interior atoms. It occurs principally on the hexagonal faces because of the layered magnetoplumbite structure.

Toshiba has been selling Ba ferrite powder since 1984 (they sell several tons per month) and a 4-MB Ba ferrite floppy disk for the past year. The disk and drive are described by Imamura (Ref 78) and by Yamamori (Ref 79). They are developing a 3.5-inch, 16-MB flexible disk (Ref 80) and will soon be marketing tape. A particularly impressive application is a Ba ferrite tape for high speed digital audio tape duplication (Ref 81). Ba ferrite has a large output even at low coercivity. A master tape and Ba ferrite slave tape with coercivity between 600 and 700 Oe are run at 4 m/s over a biasing head with their magnetic surfaces in contact. This is 327 times faster than the normal DAT playback speed.

Multilayer Films for Single Pole Heads

At any level of disk velocity, higher recording density requires higher output flux, as higher density implies wider signal bandwidth and wider band noise. Band noise in the preamplifier and coil resistance increase with bandwidth. Efforts have focused on magnetic tape and on floppy disks. They came first because in contact recording the head problem is a little less daunting. No high density perpendicular recording rigid disk has yet been marketed because, although tracking is simpler, spacing loss must be minimized; the problem of making a narrow, high efficiency head has not been solved. For satisfactory signal/noise at the reduced output signal level of high density perpendicular recording, better low impedance heads must be developed. A thin main pole head gives the resolution needed at high density, but at the cost of efficiency. A material with high saturation magnetic flux density and at the same time with high permeability is needed for the main pole.

One possibility is an Fe-N alloy (Ref 82); nitrogen enters Fe interstitially and increases the magnetization. But though Fe-N has a large magnetization (2.5 T), its permeability is not large. Other prospective materials are amorphous Co-Zr alloys, Fe-Si-Ga alloys, and Fe(Ti, Zr, Hf)C fine crystallite films, with a saturation magnetization of 1.7 T (Ref 83).

Multilayer Fe-based films are particularly promising. Their saturation magnetizations are between 1.7 and 2.1 T, and their permeabilities are large. In one approach, the material of nonmagnetic intermediate layers is not considered pivotal; the purpose of the intermediate layers is to limit grain size of the magnetic layers and thus increase permeability. There has been work on Fe/Si (Ref 84) and on multilayer films of Fe/Ni (Ref 85).

The Hitachi group, T. Kobayashi and coworkers, has been active. Fe/C multilayers were formed by ion beam sputtering (Ref 86 and 87). Coercivity and permeability are sensitive to C layer thickness. At the optimum thickness the relative permeability is 3,000 and the magnetic flux density is 1.9 T. The group next tried high permeability layers, Fe-C layered with Ni-Fe (Ref 88). Though C, like N, enters Fe interstitially, it does not increase the saturation magnetization. But it does increase the permeability. It does so by reducing crystallite size, to 20 nm or less. At 10 at. % C the magnetostriction of Fe-C goes through zero. A relative permeability of 3,000 and a saturation magnetization of 2.0 T are reported. Ni-Fe is not inserted primarily for its own high permeability; the purpose of the thin Ni-Fe layers is to block growth of Fe-C crystallites and thus increase its permeability.

Using the Fe-C/Ni-Fe multilayered film the group then fabricated a single pole head and performed read/write tests with a Co-Cr double layer tape medium with a large spread in perpendicular coercivity (Ref 89). The output was compared to that of a CZN (amorphous Co-Zr-niobate) head. It does not fall off with increasing medium coercivity. At low recording density (5 kFCI) there is not much difference between the performance of the multilayer head and the CZN head. But at high bit density (80 kFCI and 170 kFCI) the multilayer head is better. At 170 kFCI the output voltage of the Fe-C multilayer head was three times that of the CZN head.

The Fe-C/Ni-Fe multilayer film develops stripe domains and 90° closure domains. This reduces permeability. To block the formation of 90° closure domains the Hitachi group inserts very thin BN layers every four Fe-C/Fe-Ni double layers (Ref 90). The problem is that the film must be processed; it must be made part of a head. To manufacture metal-in-gap heads for high density recording, a glass bonding process at 500 to 600 °C is required. But above 400 °C grains grow in the multilayer film and the soft magnetic properties deteriorate. Kobayashi et al. (Ref 91) add Ta to the Fe-C layers. The formation of Ta carbides inhibits crystallite growth and maintains the high permeability after high temperature processing--another example of Landau's maxim.

At next year's Materials Research Society (MRS) meeting NTT will report on an Fe (7 nm)/SiO_2 (1 nm) ion beam sputtered multilayer head. For Fe layer thickness less than the critical thickness its magnetostriction is negative, and it is positive for large Fe thickness. At 7 nm the magnetostriction of the Fe is zero and the relative permeability is 2,000.

Motomura et al. (Ref 92) of NEC reported at Intermag 90 in Brighton on the soft magnetic properties and satisfactory heat stability of Fe/NiFe superlattice films for recording heads for hard disk drives. NEC's approach is to optimize the magnetic response of the material of both layers and seek the best lattice match between them. The magnetic behavior of their films is in fact a volume-weighted average of that of the materials of the two layers (plus an interdiffusion region). In films with 8 to 16 nm superlattice modulation wavelength, the saturation magnetization is 1.5 T, the permeability is 3,000, and magnetostriction is small. Interdiffusion is by thermal activation and the activation energy is 0.84 eV. Films are thus stable at operating temperatures.

A very recent discovery by Okiyama et al. (Ref 93; to be reported at the 3M conference in San Diego) merits mention. The initial and maximum permeabilities of Fe-Ni in the 34 to 46 wt. % Ni range can be enormously increased by the addition of Cr. For example, the initial permeability of Fe-36%Ni-12%Cr is 32,000, ten times as high as that without Cr. The maximum permeability of Fe-38%Ni-8%Cr is 100,000, about the same as that of Sendust. The permeability is increased by a factor of 2 by the reduction of sulfur and oxygen impurities to the 10 ppm range. The latter recognition, particularly the deleterious effect of oxygen, may be a useful caution with regard to recording head and underlayer materials.

The magnetoresistive head may brush all of this aside. But the ultimate head material for the 21st century may be the high temperature superconductor. Koshimoto of NTT has a group of eight people at the Ibaraki laboratory working on single crystal, thin film, high T_c superconducting heads.

UNCONCLUSIONS

After 15 years as a subdebutante and never a deb, one hesitates to say that Co-Cr is coming out. (What never? Well hardly ever. Toshiba, in 1982, announced the world's first perpendicular recording Co-Cr sputtered disk drive. The flexible disk did not wear well. Not many debs, least of all those that don't wear well, get to come out twice.) Barium ferrite perpendicular recording tapes and flexible disks have moved from the laboratory to the marketplace and Co-Cr (and/or Co-O?) seems poised to be next.

And yet it is not happening. Why not? One company feels there are still difficult noise problems in the underlayer. Another says they have solved all the technical problems of Co-Cr but it is a matter of economics. Of the companies I visited only NEC speaks of making a definite Co-Cr perpendicular recording product, a Co-Cr-Ta flexible disk. The hope--at present more a hope than a plan--is to market a 3.5-inch flexible disk with 25-MB capacity. (At NEC they believe that it will be possible to store 50 and 100 MB on the same size disk. Since companies want products with "extendibility," it may be that the only way the 25-MB disk will be marketed is if the 50- and 100-MB disks prove out.) The design is to use a single layer film and a ring head. Problems of downward compatibility with NEC longitudinal recording products have yet to be solved. (Since April 1990, NEC has been delivering a new 3.5-inch, 13.5-MB longitudinal recording flexible disk and floppy disk drive.) NEC has no plan to make perpendicular recording tape or rigid disks.

What may be happening is that each year as Co-Cr improves, longitudinal recording and everything else improves, too, and the threshold gets higher. A new product has to be not a little better but a lot better, and longitudinal recording is giving difficult Co-Cr a run for its money. The NEC metal, longitudinal 3.5-inch floppy disk mentioned above has a linear bit density of 36.6 KBPI and a track density of 430 TPI, and areal density is 15.7 MB/in^2, more than 25 KB/mm^2. At Intermag '90 in Brighton, U.K., IBM has announced that in 5 years they will market a gigabit density longitudinal recording system (Ref 94-97). Using a CoPtCr thin film disk, a thin film inductive write element, and a 4-micron-wide magnetoresistive read element, they have already achieved a linear density of 100 KBPI and a track density of 5,000 TPI (Ref 97). That is 500 million bits per square inch--half way to their 5-year market goal.

And then there is the tremendous promise of magneto-optics. By magneto-optical memory is meant systems in which the direction of the magnetization of the material is switched by the heat of a light (laser) pulse and read by the sense of rotation of the polarization of a sensing light pulse. In point of fact, a number of optical techniques are under investigation, and not all magnetic (Ref 8). Organic ferroelectric polymers can be erased and switched optically and the electric polarization sensed. The alignment of nematic liquid crystals (homeotropic/parallel) can be switched optically in photochromic molecular films. Alloy films of In-Te-Se, Sb_2Te_3, Ge-Te-Sb, or other mixtures can be switched rapidly between amorphous and crystalline phases by an energetic laser beam heat pulse and the optical reflectivities (or absorptions) of the two phases sensed by a lower power beam from the same laser. Japanese university, government, and industrial research laboratories are looking at these options, particularly phase change memories.

But in Japan there is a targeted effort in multilayer films and magneto-optics. The Ministry of Education (Monbusho) for 3 years funded Special Projects grants in magneto-optics. The final reports on those grants are reviewed in the preceding *Scientific Information Bulletin* (Ref 98). A program with the same goals continues in a new Monbusho project on magnetic multilayer films.

At present magnetic recording beats magneto-optics in packing bits linearly. Magneto-optical recording overcomes its disadvantage in spacing along the track by packing more tracks transversely. In the Introduction we cite 2,000 TPI for perpendicular recording. This is easily exceeded magneto-optically. The result is that areal bit densities of 675 MB/in^2, 10^6 bits/mm^2, are achieved, and as shorter wavelength laser sources become available bit density in magneto-optical recording will be further increased. Which technology will prevail? The question is too harshly posed--both approaches will have niches and advantageous applications. Bell (Ref 1) compares the relative merits and prospects of magnetic and magneto-optical recording. But one significant advantage of magneto-optical recording, already alluded to, is escape from the close tolerances of magnetic recording. In magneto-optics the laser source and sensing apparatus can be at a reasonable distance from the magnetized film. The multilayer film package can be covered with a protective transparent coating without severe cost in signal. There is no problem of head crash. The drive can be used interchangeably with removable erasable, non-erasable, and read-only media. These are important pluses.

So will Co-Cr, the precocious, rich, 15-year-old debutante come out again? NEC scientists think so, but most companies answered my query with a Japanese answer: "That is a difficult question."

"Rakugo" are old tales told by a "rakugo-ka," a story teller. Here is a rakugo that is more than 200 years old, from the Edo period. A fortune teller/mind reader sets up his stand on a street corner to amuse passers-by and solicit money. A teenager in the crowd heckles him repeatedly until the irritated mind reader calls out, "Hey kid! When are you going home?" The boy answers, "Why are you asking *me*? You're supposed to be able to tell *us* that."

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TRIBOLOGY RESEARCH IN JAPAN

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This article summarizes a series of site visits to tribology laboratories in Japan during the spring and summer of 1990. Emphasis is on the work involving materials aspects of tribology.

INTRODUCTION

The word "tribology" was suggested in 1966 for the science and technology concerned with interacting surfaces in relative motion. This is a very broad field that includes friction, lubrication, and wear. Of course, these component subjects have been of interest for many centuries. The records show that Archimedes, Leonardo da Vinci, Newton, Rayleigh, and many other well known researchers were part-time tribologists. However, they did not have available the array of modern analytical techniques that have contributed to rapid progress in tribology in recent decades.

Tribology is important for materials and energy conservation, for safety and reliability, and for efficiency in the manufacture and use of countless products in a modern society. Given the breadth of the field, it is not surprising that those who work on tribological problems have been trained in many different areas of science and technology. Tribology is multidisciplinary and progress in this field is aided by exchanges of ideas between those in different but complementary areas of research.

My own training is in materials science, so it is natural for me to concentrate on microscopic aspects of tribological processes, in particular, materials aspects of sliding wear. However, during my research leave I wanted to associate with tribologists trained and working in complementary areas. That was the basic reason for arranging an extended visit to Japan and for working with Prof. Koji Kato and his colleagues at Tohoku University in Sendai.

Prof. Kato and I planned the details of my visit so that the following kinds of activities would be included:

1. *Visits to university and industry laboratories*
2. Laboratory visits and discussions
3. Participation in tribology meetings
4. Lectures to students and researchers
5. Discussions with students
6. Sharing of research ideas and observations
7. Establishing contacts for future cooperation
8. Exploring ways to increase participation of Japanese tribologists in the planning of international tribology activities, for example, the biennial International Conference on the Wear of Materials

In this article I present summaries of site visits, with an emphasis on the work

involving materials aspects of tribology. Tribology research concentrating on lubrication and fluid flow is mentioned only briefly. Others closer to those areas of research are better qualified to describe that work.

TOHOKU UNIVERSITY

Mechanical Engineering Department

Since I was based in the Department of Mechanical Engineering at Tohoku University and spent most of my time in Japan at this university, my activities here will be described first.

I have known Prof. K. Kato for about 10 years. Our areas of research are of mutual interest. His research group of about 30 is the largest in his department. Prof. Kato participates actively in international meetings (e.g., Wear of Materials, Eurotrib, Gordon Conferences) and he has spent 1 year in the United States at the NASA-Lewis Research Laboratory in Cleveland. He is fluent in English and he emphasizes to his group the importance of English for international communication.

Of the many research projects in progress in Prof. Kato's "koza" (research group), the following topics are representative: magnetic fluid grinding, wet friction paper, rolling/sliding contact, water as a lubricant for ceramics, friction drives, machining of ceramics, ceramic coatings, scanning tunneling microscopy (STM), wear of ceramics in molten metals, effects of added particles, metal/ceramic systems, and ultrasonic drive systems. There is a healthy mix of basic and applied topics. Most of the projects are approached from a basic mechanism point of view. A few examples are described in the following paragraphs.

Several years ago the Hitachi Co. provided a pin-on-disk sliding wear test device for in-situ experiments in the Kato group's scanning electron microscope (SEM). This work, together with other experiments with and without lubricants, has led to significant progress in recognizing wear modes and understanding certain wear rate transitions. In steels, a hard pin with a rounded contact surface can cause wear of a rotating disk by the following modes: simple plowing (plastic deformation), formation of a wedge or prow of material in front of the pin, and cutting and chip formation. Samuels showed some years ago that these were affected by contact angle. Prof. Kato and his colleagues have noted that this depends on a degree of penetration (DP) parameter. The number of wear particles and the wear rate depend strongly on DP. If friction, load, hardness, and contact geometry are considered, a wear mode diagram that clearly maps the major wear modes can be developed for single-pass sliding. The bearing pressure and the sliding velocity are convenient for the axes of the diagrams. With repeated sliding, the geometry and hardness can change, and the wear mechanism can change. A new wear mechanism, shear-tongue formation, can also appear. Transitions are expected when a change in conditions corresponds with crossing from one field of the wear mode diagram to another. Such diagrams are complementary to the wear maps published by Ashby.

Another parameter that has been found useful by members of the Kato group is the ratio of the hardness of the pin to that of the disk. Their analysis indicates that this ratio should be less than one for smooth sliding and low wear rate, and most experimental results agree with this simple correlation. This is an important step toward understanding geometric effects, which have puzzled tribologists for many years.

On the more practical side, Dr. N. Umehara and Prof. Kato have developed a simple but clever magnetic fluid grinding technique for precision grinding of ceramic components. For example, silicon nitride

balls are placed with silicon carbide abrasive grains in a water-based magnetic fluid. The assembly is placed just above an array of permanent magnets of alternating polarity. Magnetic forces push the samples and abrasive grains against a rotating drive shaft. Spheres of various ceramic materials can be readily produced with desired dimensions and mirror-like surface finish. The research is being extended to optimize the process and to apply it for other geometries, including rollers, flats, pipes, and lens shapes.

Recently, Prof. Kato's group has given much attention to the wear of ceramics. Test samples have included diamond, silicon nitride, silicon carbide, alumina, and partially stabilized zirconia (PSZ). Once again, in-situ tests with the SEM have allowed identification of various wear modes. These correlate well with a severity of contact parameter based on fracture mechanics. Tribochemical effects are also being investigated. It is well known that oxide ceramics and nonoxide ceramics can behave quite differently in reactive environments such as air or water. The following are being investigated as lubricants for selected ceramics: water, solid film lubricants, and liquid metals such as zinc.

Various ceramic/metal combinations are also being studied to identify the best combinations for tribological applications. The results so far are mainly from SEM and optical microscopy, together with friction data and debris analysis. Presumably, this information will be supplemented by data on wear rates, microhardness, composition maps, and diffraction data for phase determination.

One of the most recent projects in Prof. Kato's group is on tribo-coating for space applications. A thin solid film is formed in vacuum on a fresh wear track by evaporation and condensation. Films of nanometer thickness are enough to give low friction coefficients (0.13 for Ag and 0.05 for In). The pin was 440C stainless steel and the disk was silicon nitride. Films can be renewed by repeated evaporation and condensation using appropriate duty cycles.

Future work will include study of the applicability of the STM and atomic force microscope (AFM) for tribology research.

Despite the wide-ranging topics of Prof. Kato's research, there is a general pattern to his approach to tribology research. First, it is closely connected to the interests and needs of industry. Second, there is a good mix of theory and experimental work. Third, the work is interdisciplinary: it includes mechanics, materials science, chemistry, and physics. Fourth, there is an effort to identify useful parameters and basic mechanisms of tribological processes and to display results in clear diagrams.

Other Departments

It has been known for many years that transfer of material from one sliding component to the counterface material occurs commonly, especially with metals. More recently, it has been recognized that mechanical mixing of the transfer material and surface reaction products can occur and that debris particles often consist of mechanically mixed material. The process and the results are similar to those that occur during the first stages of mechanical alloying, e.g., in a ball mill. Therefore, studies of mechanical alloying processes are relevant to studies of tribological processes, and vice-versa.

Prof. R. Watanabe is in the Department of Materials Processing at Tohoku University. His interests include powder processing and mechanical alloying. Process variables such as ball size and volume fraction have been studied. Milling is less effective as ball size is reduced. Optical metallography of processed powders clearly shows folding and kneading

of component materials. This is similar to what is sometimes observed near sliding interfaces. Prof. Watanabe finds that balls in the mill commonly become coated and that powder is generated from this coating. Again, this is similar to what happens frequently with the sliding wear of metals. With charges of Cu and Ti, the debris is typically layered, with the outer layer amorphous.

Recent work on computer modelling of ball milling is very interesting. A one-dimensional elastic/viscous (Kelvin) model is based only on normal impact. Both the impact frequency and the total energy consumption rate rise with ball fraction, but the energy per collision and the energy consumed per collision both decrease. Two-dimensional and three-dimensional models show that rotations become important.

Other research on mechanical alloying is in progress at the Institute of Metal Research (Profs. T. Masumoto, A. Inoue, and K. Suzuki). Prof. Masumoto, director of the institute, is particularly interested in amorphous materials.

MECHANICAL ENGINEERING LABORATORY

Research at the Mechanical Engineering Laboratory at Tsukuba is in seven main areas: information and systems science, mechanics and design, materials technology, production technology, energy technology, robotics and intelligent machines, and bio-engineering. Tribology research is included within the mechanics and design area.

I was impressed by the tribology laboratory and facilities and by the breadth and quality of research in progress. The work of this laboratory has been known outside Japan for many years, earlier under Dr. Y. Tsuya and now under Dr. Yuji Enomoto. The research includes tribology in hostile environments, development of new solid lubricants, sliding in various fluids, new coating methods, multiple coatings, charged particle emissions, and in-situ characterization. Members of the tribology group have been trained in several different areas, including physics, so they are able to investigate some interesting phenomena not usually studied by tribologists.

It is well known that indentation of brittle solids can cause exoelectron emission in vacuum, presumably during fracture events. Dr. Enomoto's group has detected electron emissions under atmospheric conditions from ceramics indented by an electroconductive indenter made of hot-pressed boron carbide. Signal bursts at different times have been correlated with different fracture events. The detector sensitivity is about 10^{-15} C and the response time is less than 1 μs. Negative ions can also be detected. Various test environments can be used. It will be interesting to see how this "fractoemission" technique is developed for applications in tribology.

As in many laboratories in Japan, the tribology of ceramics is receiving considerable attention. The work at Tsukuba includes tests on silicon nitride in water, methanol, n–alcohols, glycol, and their mixtures. Even small concentrations of water degraded friction and wear performance. Wear in the alcohols may proceed by surface oxidation followed by esterification reactions. Thus, tribochemistry plays an important role in these systems. Other systems in which tribochemistry is very important are boride and mixed boride/carbide ceramics. The wear of ZrB_2 in water is particularly rapid.

While at Tsukuba, I also visited the laboratory of Dr. Y. Sato in the National Institute for Research in Inorganic Materials and learned about his work on diamond films produced by plasma-assisted chemical vapor deposition (CVD). The morphology, structure, and texture of diamond films have been

studied as a function of process variables. The quality of single crystal diamond films is improved if the concentration of methane in methane/hydrogen mixtures is kept less than about 1%.

NIPPON STEEL CORPORATION, NAGOYA WORKS, TOKAI CITY

My host here was Mr. M. Sawa, who received an M.S. degree under my direction at Ohio State several years ago. He had suggested a visit because his company has experience in applying tribology for major improvements in maintenance and costs. I also met with Mr. M. Miyata, deputy general superintendent of the Nagoya Works; Mr. K. Sakai, general manager of the Equipment Division; and Mr. M. Kurahashi, who has been active in the company's ferrography program. Tours included parts of the works themselves as well as the research laboratories.

Ferrography is a technique in which a fluid containing debris particles is allowed to flow down an inclined plane through a magnetic field gradient. The particles then distribute themselves in a way that is convenient to analyze. The ferrography program at Nippon Steel has yielded particularly impressive benefits for the company in maintenance, conservation, and economic savings. For example, oil leakage has been reduced by 80% over 10 years.

More recently, the company has developed various oils and greases for bearings and gears and special hydraulic fluids, including some with high temperature and wide temperature range capabilities. This work was part of a concerted drive to reduce energy use by decreasing friction and to improve trouble-free operations by reduced wear, both by using advanced lubrication technology.

Another development by the tribology research group is a simple rotary cleaner in which lubricants contaminated by debris particles can be cleaned by passage through a chamber packed with special steel wool. The device relies on magnetic field gradients and seems to be very efficient.

The company is also experimenting with various coatings and coating processes, including coatings made with a detonation gun.

The experience of Nippon Steel in applying tribology for energy, material, and cost savings should be of interest to many other companies. Nippon Steel seems willing to share information about its successful program.

OSAKA UNIVERSITY, DEPARTMENT OF PRECISION ENGINEERING

The laboratory of Assoc. Prof. N. Ohmae features high vacuum chambers and many techniques for characterization of surfaces. These include Auger spectroscopy, laser treatment, ellipsometry, IR spectroscopy and Fourier transform IR (FTIR), mass spectroscopy, etc. An STM is being built. Projects include effects of atomic oxygen (important in space), field stimulated exoelectron emission, metal coatings, adsorption studies, supercomputer modelling, condition monitoring, sliding inside a field ion microscope (FIM), solid lubricants, and ion implantation.

The work on effects of atomic oxygen uses a CO_2 laster or a Xe spark lamp to obtain O from O_2. Materials investigated include carbon fiber reinforced plastics, MoS_2, and Ti alloys. A related project involves thermal oxidation of Si and GaAs wafers with different partial pressures of atomic and molecular oxygen. The equipment can operate up to 1,200 °C.

In another system, Prof. Ohmae does sliding experiments inside an FIM. By using sputtering and field ion evaporation he can examine the subsurface damage produced by sliding. This system has high voltage capability and, with a liquid nitrogen cold finger, samples with reasonably large tip radius can be tested.

Prof. Ohmae is also interested in using a supercomputer to calculate the friction coefficient during testing and to aid development of condition monitoring systems.

Electron microscopy is particularly active at Osaka University, e.g., in the Research Center for Ultra-High Voltage Electron Microscopy (Dr. H. Mori) and in Applied Physics (Profs. H. Hashimoto and R. Shimizu). The electron microscope specialists are not currently working on tribology projects, but their facilities and expertise are available if needed. There could be a good match of interests because the high-resolution techniques used at Osaka for fine precipitates or for amorphisation could be applied to the near-surface material produced by sliding in various environments.

KYOTO UNIVERSITY, DEPARTMENT OF METAL SCIENCE AND TECHNOLOGY

My principal host was Prof. H.P. Shingu, Metal Science and Technology. I had met him in the United States in October 1989 when he described his work on mechanical alloying at the ASM/AIME meeting in Indianapolis. The processes that occur in the first stages of mechanical alloying are very similar to those that occur when two different metals slide together, so research in the two areas is complementary.

Prof. Shingu's current research is in four different areas: control of solidified metallographic structures of alloys by fluid flow, solid state synthesis of metallic and ceramic powders, formation of nonequilibrium crystalline and amorphous phases, and crystallographic studies of metallic crystals and quasicrystals. In our discussions we concentrated on mechanical alloying and related topics.

Prof. Shingu has used ball milling and repeated rolling to obtain extensive mechanical alloying in various binary metal systems including Ag-Fe, Cu-Fe, Ag-Cu, Al-Fe, and Al-Ti. Grain sizes in the tens of nanometers are produced and sometimes supersaturated solid solutions and an amorphous phase. X-ray diffraction, Mossbauer spectroscopy, and transmission electron microscopy have been used to monitor the changes in structure. However, as in wear studies, the details of how the very fine grains are formed are not known.

Prof. Shingu has also applied thermodynamics and phase diagrams to predict systems that will form various metastable structures during mechanical alloying.

It is interesting to note an important difference between the mechanical mixing that occurs in typical sliding systems and that which occurs in, e.g., a ball mill. In the former case, material may leave the system as debris before it is completely mixed. In fact, different debris particles may exhibit different degrees of mechanical mixing. With a ball mill, however, one has a closed system, so one can obtain additional mixing by simply running the test longer. Thus, certain structures obtained with a ball mill might not be obtained in wear systems. Otherwise, the processes and structures seem to be very closely related.

Prof. Shingu is the chairman of the International Symposium on Mechanical Alloying, to be held in Kyoto from 7-10 May 1991, so he is familiar with others doing mechanical alloying research. It was helpful to learn the names of those active in mechanical alloying in Japan, including several professors working in Sendai (see earlier description, Tohoku University).

A visit with Prof. S. Miura was scheduled because of his broad interests in materials science, especially in the following areas: deformation mechanisms including effects of grain boundaries, bi- and tricrystal and two-phase bicrystal studies, superelasticity and shape memory effects, and the role of grain boundaries in corrosion and stress-corrosion cracking. Prof. Miura described his interesting work on the suppression of grain boundary sliding in Cu-Al tricrystals. Grain boundary sliding may be an active mechanism involved with the deformation of very fine grained surface material, which develops during sliding. Prof. Miura also described work on Cu–Al single crystals that were deformed by a spherical indenter both by simple indentation and by sliding. The results included measurements of dislocation density and crystallographic effects at various distances from the surface. It was concluded that the effects of normal stresses dominate below a certain depth.

TOYOTA CENTRAL RESEARCH AND DEVELOPMENT LABORATORIES, NAGOYA

My principal hosts during my visit to the tribology laboratory were Mr. J. Hasegawa, director, and Dr. Y. Mizutani, manager. The Toyota Research and Development Laboratories are described as a think tank with long term goals. The facilities for basic research are very good. In many cases the research is accomplished by interdisciplinary project teams of scientists and engineers. There are 13 research divisions, and the tribology research is included in Division XIII.

I have been familiar with the tribology research of the Toyota laboratories for many years. When I first entered the field (after working for many years in other areas of research), I noted that the papers from Toyota had a strong emphasis on materials science and were particularly interesting. This work continues with projects on all materials classes. The tribology laboratory is well equipped for wear testing. Projects are on fretting of connectors, friction of nylon fabrics, seizure, paper disks, cylinder wear, wear/corrosion, high-temperature alloys, ceramics, and coatings.

Until the last few years there has been relatively little basic research on combined wear and corrosion effects. That situation is changing as more groups turn to this relatively neglected area. The tribology group at Toyota has been studying this area for longer than most groups. Projects have included tests in various ethanol/gasoline mixtures in addition to more traditional corrosive environments such as saltwater or sulfuric acid. More recently the work has been extended to studies of friction and wear of ceramics in various environments, including air at elevated temperatures and sulfuric acid in water and in some organic solutions. The wear rate of silicon nitride was a maximum with about 20 wt. % sulfuric acid. Grain boundary corrosion was responsible. The friction of silicon carbide was reduced to very low levels in alcohols and in caprylic acid.

The work on high-temperature materials includes both ceramics (silicon nitride, zirconia, silicon carbide, alumina) and metals (Stellites, nickel-base and cobalt-base alloys). Recently, various systems involving metal films on ceramic substrates have been studied at elevated temperatures. The sliding behavior of some of these systems is quite good. In the case of alumina sliding on alumina (bare), the wear rate depends strongly on the temperature. At low temperatures the wear rate is low, perhaps because of high hardness. At intermediate temperatures the wear rate is high and is dominated by fracture. At high temperatures the wear rate becomes low again and deformation becomes more important.

IWATE UNIVERSITY, MORIOKA

Prof. A. Iwabuchi described his tribology research on amorphous alloys in vacuum, stainless steels in seawater, severe-mild wear transitions, electrodeposited coatings, behavior at cryogenic temperatures, and the effects of injected oxide particles. Prof. S. Mori concentrates on surface chemistry in tribology. His projects include studies of lubricant degradation at various loads and speeds, tribochemical reactions studied in a controlled-leak apparatus, catalytic processes, effects of EP (extreme pressure) additives (using the idea of hard and soft acids/bases), and exo-electron emission.

Prof. Iwabuchi has recently examined the tribological properties of a W-Fe-Ni-Cr amorphous coating on 304 stainless steel when paired with 304 or 316 stainless steel in vacuum. Friction was reduced compared with uncoated specimens and there was very little wear of the amorphous alloy. Results of tests of 304 stainless steel in seawater indicate that the wear mechanism involved production of fresh surface by mechanical action which, in turn, allowed continued electrochemical corrosion. In other tests, oxide particles were introduced into the system before sliding commenced. The samples were medium carbon steel and the oxide particles were alpha Fe_2O_3 with a mean diameter of 1 μm. Severe wear during running in could be eliminated if an adequate supply of oxide particles was present. Steady state wear was also reduced. Wear reduction seems to be related to the formation and re–formation of a compacted oxide layer.

Prof. Mori uses sophisticated techniques to study tribochemical aspects of sliding and cutting in various environments. For example, with a mass spectrometer he has detected many vapor species resulting from the degradation of perfluoroalkyl polyethers with 440C stainless steel in vacuum. With X-ray photo spectroscopy (XPS) he has detected metal fluorides on the surface. These both reduce the friction and act as catalysts during decomposition of the oil. Cutting of metals such as steel and nickel under high vacuum creates surfaces that are catalytically active for the decomposition of benzene and other aromatic compounds. Polar compounds such as propionic acid and propyl amine have much lower activity. Prof. Mori finds a correlation with polarizability and with Pearson's principle of hard and soft acids and bases. The cut surfaces are so active that the decomposition of benzene and certain other reactions occur even at room temperature. Freshly fractured surfaces of oxide ceramics were also found to be active enough to adsorb saturated hydrocarbons.

Prof. Mori also has studied the effects of different EP additives (phosphate type and sulfide type) on the wear of steel in air and in vacuum.

TOKYO UNIVERSITY OF AGRICULTURE AND TECHNOLOGY, DEPARTMENT OF MECHANICAL ENGINEERING

Prof. T. Yamamoto's research is on tribology in driven engines. His colleagues and he are studying the fluid flow in the engine system. He is also studying the behavior of wet paper clutch material. Prof. T. Hasegawa has broad interests in the mechanical properties of metals, including creep, fatigue, machining (especially of intermetallics), and mechanical alloying. He recognizes the similarities between mechanically alloyed material and the surface material produced during sliding. The two areas of research are complementary.

TOKYO INSTITUTE OF TECHNOLOGY (T.I.T.), MECHANICAL ENGINEERING FOR PRODUCTION

Prof. T. Sasada is well known for his contributions to understanding wear mechanisms and for his participation in international conferences. His current work focusses on surface chemistry, the chemisorption of gasses, magnetic effects, biotribology, friction catalysis, intercalation, and effects of pi-electrons in polymers. My 2-day visit coincided with two meetings, one with tribologists from key technologies and one with a group of industry people interested in ferrography. These groups are further examples of the regular interaction among university and industry people interested in tribology in Japan. They help to assure networking and a healthy exchange of information and potential opportunities.

A current focus of Prof. Sasada's work is on the chemisorption of gasses on tribological surfaces and the relation of these effects to severe and mild wear. This approach is distinct from the traditional emphasis on oxide formation for mild wear. Changes in species in the environment are monitored by mass spectroscopy. Much more oxygen is adsorbed during mild wear than during severe wear. An application of this work is friction aided catalysis, for example, the reaction of hydrogen (or D_2) and oxygen on Pd, Pt, or Ni. A magnetic field greatly increases chemisorption (and, for hydrogen, desorption) effects, but this effect is not understood at present.

Prof. Sasada has found that graphite intercalated with $CuCl_2$ is a good solid lubricant even in vacuum. He has also examined a variety of polymers in air and vacuum and finds a correlation with the amount of pi-electron bonding.

In other research, Prof. Sasada has investigated the minimum amount of oil needed for effective lubrication. Also, he has studied the effects of oxygen and of metal vapor on transfer and the formation of wear particles. Both environments increase the size and hardness of wear particles and the wear volume.

Prof. Sasada is planning retirement from T.I.T. in March of 1991, so his group is smaller than it has been in the past. His future plans include expansion of his work in biotribology.

UNIVERSITY OF TOKYO, INSTITUTE OF INDUSTRIAL SCIENCE

The institute, which is on a different campus from the engineering departments, is a part of the Graduate School of the University of Tokyo. It fosters interdepartmental and interinstitutional teams when appropriate for research objectives.

I have known Prof. Y. Kimura since 1978, when I heard him present some original ideas on wear and fatigue. His current work is in many areas: use of a modified SEM for computerized generation of quantitative surface topology information, oil mist lubrication, wear and corrosion with deteriorated oil, growth of surface cracks, use of a total reflection method to study contacts of paper clutch material against glass, X rays for studies of film thickness at interfaces, and friction of ceramics at high temperatures.

The project on ceramics uses a sliding friction and wear tester that can operate up to 1,000 °C in dry air. Alumina, silicon carbide, and sialon have been tested without lubrication. Oxidation of SiC was important at the higher temperatures used. Alumina behaved

differently from the other materials: its friction and wear decreased at higher temperatures. The effectiveness of ion-plated Ti films as solid lubricants on ceramics surfaces is also being studied. A film thickness of about 0.2 μm provides minimum friction for alumina.

NAGASAKI UNIVERSITY, MECHANICAL ENGINEERING

Prof. A. Ura described his work on the effects of loading conditions and atmosphere on fretting, sliding, and abrasion of various metals in high vacuum and geometric effects in a thrust ball bearing system. He has also collaborated with researchers at Tsukuba, Tokyo, and Fukuoka to study abrasion of metals and polymers and to compare the wear behavior of a large number of different coatings in dry and lubricated conditions.

MITSUBISHI HEAVY INDUSTRIES, LTD., NAGASAKI RESEARCH AND DEVELOPMENT CENTER

Hosts included Dr. S. Asanabe, general manager; S. Mitsutake, manager, Tribology Laboratory; Dr. S. Matsumoto, research manager, Tribology Laboratory; and S. Morohoshi, senior researcher, Tribology Laboratory. I visited both the materials research laboratories (projects on steam turbine materials, high-damping materials, high-strength materials for good resistance to high temperatures and corrosion) and the tribology laboratories (broadly divided into two areas, machine element lubrication and friction and wear under hostile environments). Both laboratories are well equipped.

The tribology research includes projects on abrasion by contaminants in oil, sliding/rolling in vacuum, precision machining, impact testing, gear testing, endurance testing, films and coatings, solid lubricants, magnetic fluid seals, magnetic bearings, laser surface treatment, high-speed bearings and seals, ferrography, and particle additives. Materials include metals, ceramics, reinforced plastics, solid lubricants, and synthetic oils. Environments include vacuum, high temperatures, and seawater.

KYUSHU UNIVERSITY, MECHANICAL ENGINEERING

Prof. Y. Yamamoto has broad interests that are reflected in the wide range of research projects he described. These include the following (with test instruments based on many different geometries): rolling contact fatigue, torsion fatigue, knee joint simulations, behavior of SiC in different atmospheres, traction fluids at low temperatures, unusual effects of viscosity on film thickness, behavior of electrical contact brushes, computer-aided encoding to relocate positions of contacts, and topographical changes during running in. Other research projects are in the following areas: effects of electric and magnetic fields on lubricant performance, effects of molecular weight distribution of mineral oils, effects of chemical composition on oil film formation and traction characteristics at high pressure or low temperature, friction and wear of ceramics, surface micro-geometry and subsurface damage in wear with lubricants, mechanical properties of electrodeposited metal films, viscoelastic behavior of polymeric fluids, and biotribology.

Biotribology is also one of the interests of Prof. T. Murakami. His studies include projects on knee joint simulation and sliding friction and wear of artificial joint materials such as ultrahigh molecular weight polyethylene, Ti alloys, and alumina. Ion-plated coatings of TiN are also being tested.

My visit coincided with a regular meeting of university and industry people from Kyushu interested in tribology. This is another example of the kind of interest group that I have met in Japan.

HITACHI, LTD., MECHANICAL ENGINEERING RESEARCH LABORATORY, TSUCHIURA

My principal host was N. Tsumaki, a senior researcher. T. Hayama is the general manager. The in-situ instrument used at Tohoku University for wear tests within an SEM was designed and built at Hitachi, and the Hitachi laboratory has a duplicate device. This was demonstrated for the case of a hard pin on 304 stainless steel. Initially the sliding was as expected for ductile metals, but the behavior then changed markedly. It was noticed that relatively large debris particles were attached to different parts of the pin surface. This was probably caused by the ferromagnetism of the BCC phase produced by plastic strain in 304 stainless. It would be interesting to repeat this test with a stable austenitic stainless steel such as 310.

The Hitachi group has continued to work closely with the Sendai group of Prof. Kato. It is continuing in-situ tests and is trying to analyze the results in terms of the degree of penetration parameter used by the Sendai group. This seems to correlate well with changes occurring as the number of cycles increases. The next step would seem to be identifying the physical mechanism(s) responsible for the correlation.

Hitachi is responsible for part of the robotic system that will be used in Japan's space program, in particular the manipulating arm. This system depends on reliable motion of various tribological components in a space environment, so this problem is receiving attention from the tribology group.

The research laboratory is modern and well equipped. Part of the work is done in a clean room facility.

DR. Y. TSUYA, TOKYO

Before her retirement, Dr. Tsuya was head of the tribology research group in the Mechanical Engineering Laboratory at Tsukuba. Now she is associated with the Kanagawa Academy of Science and Technology as well as companies in the Tokyo area, and she is chairperson of a committee that meets regularly to discuss common interests in solid lubricants and related topics. I was a participant in one of those meetings.

The work of Dr. Tsuya and her colleagues on MoS_2-based and WS_2-based solid lubricants has led to commercial products now in use in Japan. They have also developed WS_2/metal composites with good self-lubricating characteristics. Results depend on alloy composition, grain size, and volume fraction of WS_2. Recently Dr. Tsuya has helped to coordinate comparative tests at various laboratories on a variety of lubricants, some with and some without solid lubricant additives such as MoS_2 and graphite. The results are being incorporated in a new data bank that should be very useful to industry when it is ready. A tribology data bank is also being developed at the National Institute for Standards and Technology (formerly the National Bureau of Standards) in the United States. As a result of this visit, each group is aware of the work of the other group; perhaps some sharing of methods and results will help both.

Dr. Tsuya is also interested in ceramics, and she recognizes that some of the same problems that afflict metals in tribological applications are present with ceramics also. She has emphasized the importance of initial contact conditions (point versus line) and the need for special lubricants in many cases.

One of the special topics discussed at the committee meeting in Tokyo was the problem of environmental impacts of widely used refrigerant materials related to Freon. There are many possible alternatives that would be less harmful with respect to destruction of the Earth's ozone layer and the greenhouse effect, but most of them may be less effective as lubricants, e.g., in car air conditioners. Preliminary data on friction and wear were presented and various options were discussed. Apparently, there is some good long-range planning in progress in response to worldwide concern about environmental impacts of widely used refrigerant fluids, and tribology research has a role to play in this effort.

KANAZAWA UNIVERSITY, FACULTY OF ENGINEERING

Prof. K. Tanaka is well known for his work on the friction and wear of polymer materials, but he also works on a wide range of other materials. Recent work on polymers is on polyetheretherketone (PEEK), aromatic polyamide (ARAMID), and polyethersulfone (PES). For PEEK and ARAMID on steel, there was low friction and little dependence of friction on sliding velocity. The friction of PES was much higher. On glass, the ARAMID friction was lower than for the others. Wear of PES and PEEK was much lower on glass than on steel, despite the higher temperatures from frictional heating with the insulating counterface material. Sliding behavior was strongly influenced by transfer characteristics in all cases.

In other recent work, Prof. Tanaka has studied the effect of temperature on composites of PES, PEEK, PAI (polyamide-imide), and PTFE (polytetrafluoroethylene) with various fillers; effects of sputtered coatings (1 μm) of BN, silicon nitride, and titanium carbide; and the friction and wear of floppy disks (life increased with increasing fractions of filler and lubricant) and hard disks. In the latter work, carbon protective layers were used and carbon transfer to the head was detected. Friction increased with multiple passes, but the increase in friction did not correlate directly with wear. Friction increases were greater for the usual circumferentially abraded surfaces than for smooth surfaces. Lubricants were effective in maintaining lower friction with multiple passes.

Prof. Tanaka will retire in March 1991, but he plans to continue his tribology research by cooperation with colleagues in industry.

Prof. Y. Uchiyama's special interest is the tribology of elastomers and plastics. The work includes tests above and below room temperature and effects of different atmospheres. Abrasion of various polymers at different temperatures correlated well with glass transition and melting temperatures. Fiber-reinforced rubber behaves very differently depending on the orientation of the fibers relative to the sliding direction. The wear is greatest if the fibers are in the plane of sliding but normal to the sliding direction. Interferometry is being used for tests of rubber on glass. Tests with ice (transparent) versus rubber at various temperatures have practical significance for transportation.

SOME GENERAL IMPRESSIONS

I have learned that the connections between academic research groups and industry are quite good in Japan. This extends beyond the usual sponsorship of research projects. Industry people regularly visit university research groups for discussions about current or future research. Also, I learned that several university tribology groups have organized regular meetings with interested scientists and engineers from industry and from other universities. These are in the Tokyo area

(Prof. T. Sasada, Dr. Y. Tsuya); central and northern Honshu (Prof. K. Kato); and Kyushu (Prof. Y. Yamamoto). Each meeting seems successful, i.e., interesting and mutually beneficial for the participants. If similar organizations were set up in the United States, similar benefits would be expected. Note: Later I learned from Prof. Uchiyama that other tribology interest groups are also active in Japan.

The equipment and instruments used for tribology research seem to be of good or excellent quality. However, some of the buildings in which they are housed, even at major universities, and especially at engineering campuses, are old and could use major improvements or replacing. This would be for more than aesthetic reasons. It is difficult to maintain contamination-free conditions and to control temperature and humidity in many of the buildings I have visited. One of the few exceptions during my travels in Japan was the Mechanical Engineering Laboratory at Tsukuba.

The "koza" structure and the faculty system in Japan are quite different from the corresponding systems in the United States. The Japanese system is more hierarchical, with junior faculty assisting senior faculty, whereas junior faculty are independent and have duties similar to those of senior faculty in the United States. Both systems have advantages. In the United States, an excellent young person can move ahead quickly. On the other hand, there is very high pressure on young faculty in the United States, and some of them could use the training and mentoring that the koza system provides.

In classes and seminars I have found that students in Japan are reluctant to ask questions or present comments. Perhaps part of this is a feeling that a nail should not stick out. Perhaps part is related to respect for elders and for those higher in rank. Personally, I enjoy questions from students and I encourage them in my lectures and seminars. Most of us in the United States feel similarly on this point, and we count it a success when a student becomes more adept at questions and discussion during his or her time with us.

For some years we have tried in the United States to increase the number of young women entering science and engineering programs. We do this by mailings to selected high schools, by workshops for teachers, by open houses and visits to our university (for students and parents), by scholarships, by arranging summer jobs, by having successful women engineers contact prospective students, and by publishing articles in newspapers and magazines about women in engineering. The number of women in science and engineering in the United States is still small, but it is much larger than in Japan. The only women students I have met at engineering departments in Japan have been from other countries, mainly China. At nonuniversity laboratories, only one researcher was a Japanese woman. I include this observation because it is a noticeable difference between Japan and many other countries. It seems that a valuable resource is being ignored.

I was surprised to learn about the rather strict rules on retirement from major universities in Japan. In the United States, many universities currently have an age limit of 70 (65 for chairmen), but pressure from age discrimination laws may soon eliminate even that limit. The age limit in Japan varies somewhat (60, 63, 65, etc.), and it is common for an active professor to resume his career at another university after reaching his university's mandatory retirement age. Still, there are inevitable interruptions in productivity. The more active researchers are valuable resources for Japan, so I wonder if some way can be found to use their talents more effectively.

I have noticed increasing international activities in Japan. This includes participation in international meetings. Perhaps the contacts I have made will help us to expand the international participation of researchers from Japan in such conferences as the International Conference on Wear of Materials (WOM). The organizing committee for WOM is discussing the feasibility of holding one of our future conferences in Japan. Preliminary discussions with Japanese colleagues have begun.

Tribology research is very active in Japan and it seems to be growing both at universities and in industry. From my visits and discussions I received the impression that there may be more research on chemical, physical, and materials aspects of friction and wear in Japan than there is in the United States. True, retirements are reducing the tribology activity at some locations, e.g., Kyoto University and Tokyo Institute of Technology, but tribology research in many places is thriving.

David A. Rigney is a professor in the Department of Materials Science and Engineering at The Ohio State University. He received degrees from Harvard University (A.B., 1960; S.M., 1962) and Cornell University (Ph.D., 1966). His publications are (chronologically) in the areas of work hardening, solidification kinetics, phase diagrams, nuclear magnetic resonance and electromigration of liquid metal alloys, and friction and wear. From 1975 to 1988 he was deputy editor of the journal *Scripta Metallurgica* (acting editor, June-December 1988). He has served as a member or chairman of various committees for the American Society for Metals (now ASM International) and AIME, and he is a Fellow of ASM. He is conference chairman for Wear of Materials 1991, to be held in Orlando, FL. During the spring and summer of 1990 he was a visiting professor in the Department of Mechanical Engineering at Tohoku University in Sendai.

THEORETICAL CHEMISTRY IN AUSTRALIA: A History of Leadership and Excellence

P.P. Schmidt

For over four decades, the Australian contributions to the development of theoretical chemistry have been substantial. In this article, the Australian university system is described and the current Australian activity in theoretical chemistry is discussed.

INTRODUCTION

For over four decades, the Australian contributions to the development of theoretical chemistry have been substantial and, I believe, greater than the numbers of individuals involved. Over the past decade and a half, theoretical chemistry in general has matured to the point of being able to provide, in a growing number of instances, *a priori* molecular properties based on calculation, not physical experimentation. Indeed, a new branch of experimental science has evolved from the efforts of theoretical chemists, *numerical experimentation* or *computational chemistry*. The Australian connection to this development is substantial; the Australian influence is dominant in two areas: molecular electronic structure and the associated spectroscopies, and the statistical mechanics of polar systems, in particular, electrolytes.

So much has been said recently about the explosive growth of computer capability that many people believe we are able to make complete scientific predictions without the need for experiment. This is hardly the case. There are indeed interesting and important gaps into which the technological computer revolution has only begun to reach. It is certainly safe to say that one now has the *capability* to carry out impressive calculations, the aim of which are to model the world around us starting from some fundamental assumptions. Nevertheless, the public at large is not yet aware that this technology is only beginning to be used or, in fact, even *able* to be used. The problems that we have solved so far, although impressive from a purely scientific standpoint, concern fairly small systems under relatively ideal conditions. But, since that which has been accomplished is such a step from the abyss, we can all be excited about the journey ahead.

Until approximately 20 years ago, chemistry was predominantly an experimental science; there was, nevertheless, a small number of individuals whose single interest concerned theory. Although it was generally held then that chemical theory was important, it was believed equally by many that until it was capable of both accurate duplication of experimental numbers and predictability, it was little more than an interesting sideline, the occupation of a relative few. Theory had then, and still has, two main branches: quantum mechanics and statistical mechanics. After

Schroedinger's wave mechanics appeared in 1926, effort was immediately applied to the application of quantum mechanics to real molecular problems. It is accurate to say that in the time prior to digital computers, an important part of the general structure for the approximate, but possibly accurate, solution of the quantum molecular problem was established. The character of the covalent chemical bond was established even though it was difficult to obtain specific numerical values for complicated molecular systems.

Quantum mechanics has its origins in Denmark and Germany with important input from England and the United States, and statistical mechanics has its origins in part in the United States, through Gibbs, and in Germany, through Boltzmann. Once established, the growth of quantum and statistical mechanics became a global concern. The development of many of the chemical applications of quantum mechanics and a large and important part of the statistical mechanics of polar solutions can be attributed to a smaller group of individuals of whom the Australian contribution over the last 40 or more years has been very important.

In the following, I briefly sketch a little of the background to the Australian contribution and I discuss some of the current Australian activity in theoretical chemistry.

THE AUSTRALIAN UNIVERSITY SYSTEM

In comparison even to the United States, the Australian university system is young (Ref 1). Indeed, better than half of the present system was established after World War II. The oldest universities are Sydney and Melbourne, established in the 1850s. Interestingly enough, in 1939 the total undergraduate population in Australia was 14,200 students. The growth of the Australian university system did not match that of the European countries and countries of European origin (e.g., the United States, Canada, and several of the Latin American countries). Until the discovery of gold in Australia in the 1850s, colonialization consisted of relatively small communities. And, when the population did begin to grow, growth occurred in the states of New South Wales and Victoria, and in the cities of Sydney and Melbourne. In addition, until the development of an extensive system of secondary school education, there was not a significant population of eligible students.

Almost all of the universities were established by the state governments. This is similar to the land-grant and state university systems established in the westward movement in the United States, but in contrast to the development in the United States of an extensive collection of private, generally religiously based colleges and universities. Australian universities have from the beginning relied on government support and this direct government support continues.

There has been, in the Australian university system, an increasing participation of the federal government in both regulation and financing as opposed to allowing the responsibility to remain largely in the hands of the states. The intake of students certainly at the undergraduate level is largely local. In some cases, with professional schools and with programs keenly competed for, student intake is restricted to state residents, not unlike veterinary schools in the United States.

The faculty members who are responsible for both the undergraduate and graduate education are drawn from fairly wide sources, but most are male and Australian. The Australian universities have generally granted permanent staff, at the rank of lecturer and above, leave, including overseas leave, for 12 months at full pay after 6 years of service. It is generally the case, especially in the sciences, that the instructional and research staff members have spent time abroad, generally in the United Kingdom or the United States. Thus, contacts between

Australian researchers and the rest of the world are good. In view of the great distances involved in getting from Australia to other parts of the world, for scientific conferences, for example, it is not surprising to find that attendance is perhaps a little more selective. Nevertheless, many count on seeing Australian colleagues at meetings in the United States and Europe on a regular basis.

For Australian nationals, undergraduate and graduate education is without immediate cost during the time of study. The individual repays the state with a surtax that begins sometime after completion of studies and is based on the level of earnings. In view of the reckoned cost to the state to educate an individual, the Australian Government imposes a fairly steep student charge (essentially a visa tax) on all foreign students who wish to pursue study in Australia. Apart from living costs, there are few additional fees. There are some who are concerned that the size of these fees may discourage foreign students from Australian universities and thus shrink the pool of able researchers at the postgraduate level. While this certainly seems a possibility, the true impact of the policy deserves the test of time. I note that the United Kingdom also imposes a stiff visa tax on individuals seeking to gain an education in British universities. Finally, the Australian Government does not impose a visa tax on postdoctoral fellows and on fellowships. These fellows are seen properly as contributing to the growth of science in Australia.

RESEARCH SUPPORT

As in most countries, there is a federal mechanism for research support. In Australia it is tied, for the most part, closely to the overall university allocation. This mechanism *has advantages and disadvantages just like any* other system. There is less active grant proposal writing, but I understand from conversations with several people that the lack of competition was felt to be somewhat of a disadvantage. Those with whom I talked who were also familiar with the American method of seeking support for research felt that an element of free competition, and especially competition with *peer* review or with peers involved somewhere in the approval process, was needed in Australia. There seems to be more than a little discontent with what was expressed as the civil servant administration of highly technical research.

In addition to worries about the small level of peer participation in the administration of science, there was an interesting worry concerning a new thrust on the part of the government to de-emphasize basic research* and to encourage more socially and technologically relevant research. This concern was interesting to me simply because it brought back memories of similar concerns of American scientists voiced about 20 years ago. Several people anticipated difficulty in trying to justify their research without a particular application in mind. The need for justification may be a burden; in contrast, the focus on specific objectives of many of the U.S. granting agencies places that burden more onto the scientific officer who is in a position to select research that has a reasonable potential application. This push toward a more practical end will probably not be all that troublesome. Practical necessity has always driven science, even if subtly. I think many American scientists found, once forced to live with technological objectives, that practical needs often suggest basic scientific issues that had been ignored, forgotten,

* As reported in the *New Scientist*, 7 October 1989 (p. 23), the Australian Science and Technology Council recommended that in light of insufficient levels of funding, there is not enough support for the level of basic research by all who want to carry it out. The Council recommended consolidation of resources to support a smaller number of able individuals. The report also notes, naturally enough, considerable protest on the part of Australian scientists.

or buried. It is amazing just how much basic science is driven now, for example, by the need for new high density power sources.

AUSTRALIAN THEORETICAL CHEMISTRY

The character of Australian science, particularly theoretical chemistry, evolved in large measure from the experiences of a group of scientists who sought to complete their education in the United Kingdom immediately after World War II. At that time, as indicated earlier, the Australian universities were only beginning to offer the Ph.D. degree. Several individuals, for example, David Craig, Allan Maccoll, Andrew Hurley, R.D. Brown, A. David Buckingham, Noel Hush, and others, completed their tertiary education in England. Among the Australian scientists who left for England in the late1940s and early 1950s to complete their education, Andrew Hurley, David Craig, R.D. Brown, and Ian Ross returned to establish very strong groups in theoretical chemistry, groups that continue today. In addition, Noel Hush, who for a long time held positions at Bristol in the United Kingdom, returned to Sydney to build the School of Theoretical Chemistry. Of course, many other Australians remained abroad; nevertheless, their influence should be included with that of those who stayed or returned to Australia.

There is active interest in molecular structure theory that includes large scale *ab initio* calculations to obtain accurate electronic and molecular structure. Associated with this is an interest in molecular spectroscopy; this interest spans issues of high resolution vibronic spectroscopy of species in the gas phase as well as the spectroscopies of condensed phase matter, particularly the spectroscopy of molecular solids and the associated exciton problem. The statistical mechanics of polar fluids and electrolytes has been a dominant interest of a number of first class researchers at several universities for a number of years. A significant part of the pioneering, and relatively recent, advances made in the statistical mechanics of the electrical double layer is due largely to Australian efforts. The role of this work in the theory of oxidation-reduction reactions and in the general understanding of biological charge migration (ionic and electronic) is important.

In the following paragraphs, I survey the work of several individuals whose work typifies the research interests I referred to above. At this point, I must apologize to those individuals whose work I fail to mention. I plead the bias of my own interests in the selection and beg indulgence of those not included. I do not by any means intend to imply any greater worthiness by virtue of the topics and individuals I have chosen for focus.

THE AUSTRALIAN NATIONAL UNIVERSITY, CANBERRA, A.C.T.

Professor D.P. Craig, F.R.S., formerly Dean of the Research School of Chemistry, and among the first of the professors of the school, is certainly one of the best known of the Australian theoretical chemists. His research covers a period from the late 1940s and continues at the same pace today. His interests span a variety of areas and his contributions to each are considered to be ground breaking. A list of the highlights includes his early work on bonding theory, his experimental verification and theoretical development of the Frenkel molecular exciton, early contributions to the theory of vibronic interactions and, over the last two decades, an extensive body of work on molecular quantum electrodynamics and retarded interactions.

Although retired from the Research School of Chemistry of the Australian National University for several years now, Professor Craig continues his research having moved a few feet away into the Chemistry Department

of the School of General Studies. Among Craig's recent publications is a treatment in the form of a soluble problem of the adiabatic approximation in vibronic coupling (Ref 2) and a treatment of third-body mediation of resonance coupling between identical molecules (Ref 3). The former problem is one that refuses to go away; what is the proper and accurate separation of electronic from vibrational motion, and can one trust the separations made. The latter problem is important for a number of phenomena from spectroscopic excitonic response to energy transfer and degradation. One interesting application of quantum electrodynamics to chemical problems was the development of the theory of chiral interactions that was carried out more than 15 years ago by Craig, Power, and Thirunamachandran. Professor Craig maintains an interest in this area; in particular, together with Dr. T. Thirunamachandran, University College London, he has recently reported the results of investigations of changes in chiral properties brought on by intermolecular interactions and the chiral-achiral interaction between molecules.

The Research School of Chemistry of the Australian National University can also boast in having on its staff probably the foremost *ab initio* theorist in Australia and one who is very well recognized throughout the world, Leo Radom. Leo has had a long standing working partnership with John Pople, who is known for his contributions to the development of both the semiempirical and *ab initio* quantum mechanical methods now in use: namely, the complete neglect of differential overlap (CNDO) method of approximation and the Gaussian series of programs. Leo has had an important impact on the development of the Gaussian quantum chemical programs that are increasingly used throughout the world.

Leo's recent interests center on the electronic and molecular structure of small molecular ions; the continued improvement and development of large scale, multiconfigurational quantum chemical computations; and the determination of potential energy surfaces. In particular, recent work (Ref 4-7) involves the potential energy surface of $C_3H_4^{2+}$, the structure and stability of multiply bonded argon-containing ions, isoelectronic analogs of molecular nitrogen, as well as investigations into the determination of heats of formation of a number of molecular species. The importance of this work is in the perfection of theoretical and computational means of estimating useful energetic quantities and molecular parameters that can be employed both for predicting trends for synthesis and for enhancing our general understanding of chemical regularity among classes of compounds. Theory has always been the microscope on the atomic part of the universe. The related computations amount to the fine focus. The detail revealed is certainly worth the effort.

There is a great strength, as indicated, in Australia in statistical mechanics. Much of this work is carried out in departments of physics and applied mathematics, but the context is frequently chemical or biochemical. Some of the issues addressed by the statistical mechanics community involve energetics, the thermodynamics of systems, and some involve time-dependent transport and reactive kinetic phenomena.

R.O. Watts, for a long time at the Australian National University, moved recently to the University of Washington. Watts' contributions to vibrational spectroscopy in recent years are equal in novelty with his contributions to statistical mechanics and Monte Carlo and molecular dynamics calculations a few years before that. In recent years, Watts and his colleagues explored the use of quantum Monte Carlo techniques to obtain accurate, and fully anharmonic, predictions of the vibrational spectra of several small molecules (Ref 8 and 9). The quantum Monte Carlo (MC) technique offers the possibility of carrying out

fully accurate calculations. No perturbation theory is involved; there are no truncation problems, although there are indeed other, different problems for some systems. For the vibrational problem it is possible to carry out the calculation of excitation frequencies, and it is possible to try—again through the medium of the MC simulation—to model the effect of solvent on the spectrum. This type of work is beginning to be done. Watts' work, with that of his colleagues, constitutes a real breakthrough. One can reasonably expect to see definite, experimentally verifiable, results from the calculation of solvation effects.

Barry Ninham, Department of Applied Mathematics, the Australian National University (ANU), has for years pursued interests in transport and membrane phenomena. A particular focus has been on systems of biological importance. Alone and in collaboration, Ninham has expanded double layer theory applied to membrane systems in particular. Recent publications, in collaboration with D.J. Evans in the Research School of Chemistry, ANU, have dealt with double layer and solvation forces and interfacial tension in ionic microemulsions, to mention only two topics.

D.J. Evans is very productive with a range of interests, reflected in publications, covering nonequilibrium statistical and thermodynamic issues to the membrane systems just mentioned above (Ref 10-17). The majority of his work concerns fluid mechanics as developed from statistical mechanics both formally and through computer simulation. Both from the formal theoretical point of view and for computational statistical mechanics, this body of work extends the limits of applicability. The calculation of thermodynamic quantities for fluids, based on simulations, has been a topic of central concern from the beginning. The use of limited collections of atoms and molecules, in a simulation, to represent extended systems was a breakthrough. The specification of boundaries consistent with statistical mechanical and thermodynamic constraints continues to receive attention. Although the major problems have been resolved, and resolved long ago, the use of simulations to extract information about systems under unusual conditions (as, for example, the chemically reactive transition state) is only beginning to be explored extensively. The work of Evans and his colleagues is an important addition to the analysis of interesting chemical and physical systems under both equilibrium and, especially, nonequilibrium conditions.

Another member of the Research School of Chemistry, ANU, is Michael Collins. I first was aware of his work through his review article on solitons in 1983 (Ref 18 and 19). Collins has pursued chemical applications of soliton theory through a number of recent publications. Some of the soliton theory finds application in resonant energy transfer. Another believed manifestation of soliton behavior is connected in some types of conducting polymers. Research of this kind continues to be of great interest in view of the efforts to find new, usually polymeric, materials with metallic or near-metal-like properties. In addition, he has interests in chemical reactivity, having recently looked at issues connected with chemical reaction coordinates (Ref 20).

Finally, with respect to the Australian National University, it is worth mentioning one more expatriate, namely Jacob Isrealachvilli, who moved from Canberra to Santa Barbara a few years ago. Over the years, Isrealachvilli has contributed importantly to our understanding of atomic and molecular forces of interaction between nonbonded species. His greatest fame is associated with the atomic force microbalance method he pioneered and with which it is now possible to probe the actual behavior of mean field, long and short ranged potentials.

AUSTRALIAN DEFENSE FORCE ACADEMY, A.C.T.

Eric Magnusson, Chemistry Department, Australian Defense Force Academy, Australian Capitol Territory, has made contributions to theoretical chemistry for a number of years. I first learned of him through his association with D.P. Craig and their efforts, some time ago, to find efficient numerical methods for the evaluation of many-center quantum chemical integrals. Magnusson has recently initiated a series of interesting papers (Ref 21 and 22) exploring the old, but nevertheless important, chemical issue of the nature of the change in electronic charge distributions as atoms move from the free state to molecular association. By investigating the changes that take place in atomic orbitals in the process of bond formation, within the context of the Hartree-Fock approximation, Magnusson has been able to determine that the concept of equalization of electronegativity involves some charge transfer and some orbital deformation. It is possible to give quantitative estimates of each. The concept of the equalization of electronegativity implies charge transfer, much as the Fermi levels of two metals distort through electron redistribution to match at the interface. Even when homonuclear bonds are formed, as with H_2, for example, there is some charge transfer along with the orbital deformation.

UNIVERSITY OF SYDNEY, SYDNEY, N.S.W.

Over the past 15 years or more, the theory group at Sydney, with Noel Hush's direction, has continued to pursue interests in the theory of chemical reactions. Noel Hush is, of course, well known for his contributions to the theory of the electron transfer reaction, worked out in the late 1950s at about the time R.A. Marcus proposed his version of the theory of the same processes. In 1967, Hush proposed an explanation of the then novel phenomenon of intervalence electron transfer that has been developed extensively since then by him and others. The intervalence transfer theory gives important insight not only to the electron transfer between metal atoms bound together over relatively short distances but to the important topic of biological electron transfer.

Hush and collaborators, in particular G.B. Bacskay (Ref 23), have recently been looking at the use of *ab initio* calculations with optimal, but not overly large, basis sets to calculate important molecular and spectroscopic properties, concentrating on SO_2 recently. They calculated the infrared (IR) and Raman transitions for SO_2 and found reasonable agreement with experiment; accurate derivative routines were used as an integral part of the calculation, although it was necessary to accommodate the Hellmann-Feynman theorem with adjustment of the nature of the wavefunctions used. The results were compared with similar computational results obtained for ozone. Comparison of the SO_2 results with those for O_3 show that the configuration interaction (CI) single-double excitation level of approximation is adequate to account for the differences observed. One's ability to predict accurately molecular properties with *ab initio* methods is important to the overall goal of understanding chemical processes, phase transformations, and reactivity. The theory group at Sydney has been instrumental in providing needed insight into chemical processes.

Much of the work on electronic structure theory carries with it the implicit application to the problem of the absorption of light by the electronic degrees of freedom. Although there continues to be interest in this important problem, the emphasis has shifted recently to the examination of vibrational transitions. The reason for this is reasonably clear; the vibrational transitions within a molecule are usually

much more sensitive to the subtle effects of the solvent or solid host that surrounds it. As such, one can anticipate learning much more about environmental interactions from the careful study of a vibrational spectrum than one usually expects to be the case for a purely electronic transition. Of course, no electronic transition takes place (except in an atom) without the interplay of molecular vibrations. Within a single molecule, however, this problem is reasonably well understood. There is considerable excitement now over the renewed prospect of using vibrational spectroscopy as a sensitive probe of solute-solvent interactions.

Mark Sceats, School of Physical Chemistry, Sydney, is investigating stochastic models for diffusion, including friction effects (Ref 24-26). Part of the work is formal, and theoretical, and part involves molecular dynamics simulations. From the molecular dynamics simulations it is possible to extract values for the correlation functions, and these values, in turn, can be manipulated to obtain friction and diffusion coefficients. A significant application has to do with energy transfer between molecules and with vibrational energy relaxation from excited states. Energy transfer and relaxation are involved in such highly diverse problems as friction and wear and photosynthesis. A clear understanding of energy and transfer mechanisms will, one hopes, lead to a much better understanding of photosynthesis, for example.

UNIVERSITY OF NEW ENGLAND, ARMIDALE, N.S.W.

Mark Spackman, Department of Chemistry, University of New England, is an individual with a background both in physics and chemistry. His interest and association is with the crystallographic community. However, his recent publications (Ref 27-30) indicate a depth of interest that is far broader. Indeed, one of his more interesting efforts has been to develop a simple, yet still quantitative, model for the strong hydrogen bonds that exist in some systems. It is frequently asserted that hydrogen bonding has a large electrostatic component. In order to reconcile this, it is necessary to construct a suitable repulsive potential energy function. By means of a suitable choice of potential energy functions, Spackman has managed to predict bonding in situations where hydrogen bonding is expected from *ab initio* calculations to within a few percent of accurate values. Spackman is also interested in the accurate prediction of static dipole polarizabilities with the use of relatively modest sized sets of basis functions. He achieves good results, even with small basis sets, because it appears that many-body perturbation theory accounts for the majority of the correlation effects.

UNIVERSITY OF NEW SOUTH WALES, WOLLONGONG, N.S.W.

C.J. Hamer, School of Physics, University of New South Wales, is interested in the use of Monte Carlo calculations in connection with quantum electrodynamics. In a number of papers (Ref 31 and 32), Hamer and colleagues have used the renormalization group for surface and lattice models. J. Oitmaa, of the same department, has been looking at several issues connected with Ising and lattice models, in particular, memory functions, phase transitions, and Monte Carlo studies of critical behavior (Ref 33-36). The importance of this work to chemical physics is tied to the continuing interest in lattice statistics as representative of a number systems of interest from liquids to crystalline solids. In particular, the theory of phase transitions continues to evolve from the use of the Ising model.

UNIVERSITY OF TASMANIA, HOBART

F.P. Larkins, Chemistry Department, University of Tasmania, has interests in the theory of Auger spectroscopy. Recent work (Ref 37 and 38) involves x-ray emission processes for molecules, determined via *ab initio* calculations for the N_2O, the Auger-electron spectra for the fluoromethanes, and an *ab initio* study of the chlorine x-ray emission spectra for the CH_3Cl. There has been an ongoing interest in several groups in the theoretical prediction of Auger spectra. This type of research is important for the sensitive information it gives about molecular fine structure; much of this structure can only be revealed through theoretical analysis and its use to interpret spectra.

UNIVERSITY OF MELBOURNE, MELBOURNE, VICTORIA

Derek Chan, previously at the Australian National University, now at Melbourne, is also a pioneer in the development of the statistical mechanics of double layer phenomena. In addition, Chan has a strong interest in the statistical mechanics of electrolyte solutions. This is a particularly difficult area in which to work. The long range Coulomb interactions, together with the fact that these solutions are overall electrically neutral, and therefore mandate collections of oppositely charged species, necessarily lead to complicated, coupled equations to describe the phenomena. He has recently been interested in problems of simulating flow in porous media and diffusion of ions in Coulombic fields (Ref 39 and 40). A relatively new interest is in characterizing properties, for example, the refractive index gradient, in human lenses.

LA TROBE UNIVERSITY, MELBOURNE, VICTORIA

Another mathematician with interests that bridge into chemistry is E.R. Smith, La Trobe University. Much of his work is with mean spherical models (MSA) involving Coulomb interactions. The MSA is one of the better known approximations used to obtain solutions of the Percus-Yevick equations in statistical mechanics. Indeed, many of the advances made in electrolyte solution theory over the past 15 years have involved these equations in one way or another. One area of great interest addressed by Smith has to do with the appropriate boundary conditions imposed on the unit cell in a Monte Carlo simulation. A traditional approach has been to use a minimum image model; a particle in the unit cell interacts with the nearest image in the 26 replicas that surround it. There are instances where this approximation breaks down. Recently, Smith has worked to get around this problem for thin layers. In addition to this work, Smith has a number of papers in the past few years touching important aspects of transport theory, hydrodynamics, and dielectric phenomena in solution (Ref 41-45).

UNIVERSITY OF WESTERN AUSTRALIA, PERTH, W. AUSTRALIA

Mark Gould, now Department of Mathematics, University of Queensland, and Graham Chandler, Department of Chemistry, University of Western Australia, have recently been exploring unitary group formulations to sort out configuration interaction calculations (Ref 46-49). The CI level of improvement of the Hartree-Fock-based calculations is an important one and forms the basis of much of the *ab*

initio work that is carried out. Configuration interaction essentially creates and mixes excited state configurations for the electrons into the original ground state system. In so doing, it is possible to make amends for one's excessive simplicity in the original choice of ground state high frequency (HF) wavefunction. The CI method is a rational approach to the improvement of the system basis set without invoking an overlarge and arbitrary collection of functions to solve a particular problem. In order to be efficient, however, it is necessary to be able to sort internal, core electrons from the more "active" outer electrons. Thus, the decomposition worked out via a unitary group representation by Gould and Chandler offers the possibility of efficient calculation by forcing the algorithms that follow from the theory to concentrate on the optimization of the most sensitive part of the system, the electrons in the "active space."

CURTIN UNIVERSITY, PERTH, W. AUSTRALIA

Steven Carnie, at the University of Western Australia, who a decade ago began working with Derek Chan, is also one of the leaders in the development of the theory of the electrical double layer (Ref 50 and 51). The distribution of charge and associated potential across the interface that separates a charged electrolyte solution from a metal surface is crucially important to the charge transfer processes and chemical reactions that take place. The understanding of this region has been a major topic of interest to electrochemists for all of this century and the latter part of the last. Until about 15 years ago, the only theories that existed to account for double layer charge effects were based on continuum models, essentially the Gouy-Chapman theory that bears a similarity to the Debye-Hückel theory of electrolytes. The statistical mechanics community, of which the Australian representation is strong, began to apply rigorous analyses to the charged interface, metal-solution system. As a result, it is increasingly possible to characterize this important system in terms of realistic models. Carnie, in particular, has had a close association with John Valleau and members of his group in Toronto. Over the past 10 years, Valleau, Carnie, and their associates have pioneered both the development of new theoretical methods and computer simulations to account for double layer phenomena.

CONCLUSION

It has always seemed remarkable to me that a country with the relatively small population of Australia (barely larger than that of the largest cities in the United States) should have such a large influence in the world, an influence that seems, for theoretical chemical physics in particular, much larger than the number of individuals involved. Australia over the years since the end of World War II has produced a number of first rate scientists in many areas, and in chemical physics in particular, who have spread out, like a diaspora, to carry their particular brand of science to the world. At the same time, it has also seemed a little sad that because of the smallness of the population, and the associated limited opportunity for so many well-trained people, emigration frequently was the only option for appropriate employment.

I first became aware of Australian science through my acquaintance with Tom Dunn, an expatriate Australian at the University of Michigan, years ago. I was attracted to and spent time in Australia finishing my formal education as a postdoctoral fellow a number of years ago. I recall, still with amusement, David Craig's comment to me in London a

year before I moved to Australia. He noted that everyone passed through London; thus, by staying at University College, I would benefit from a broad and frequent exposure to well-known scientists. The next part of the comment was that almost no one passed through Canberra. He was wrong, I am very glad to say. Australian science, and especially Australian scientists, command world-wide respect. There is a vitality that is well known and that attracts both long and short term visitors. I have seen no lessening of the quality or quantity of Australian scientific productivity for over 20 years.

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THE FIRST JOINT MEETING ON DIVING AND HYPERBARIC MEDICINE

Kenneth C. Earhart

This conference covered topics in hyperbaric oxygen (HBO) therapy, diving medicine, and basic sciences pertinent to both fields. In addition to a brief discussion of the development and future of HBO therapy, this article also describes recent advances in diving medicine in the areas of etiology and bubble formation, decompression sickness, physiology, detection of bubbles, deep diving, and data collection and analysis.

INTRODUCTION

The First Joint Meeting on Diving and Hyperbaric Medicine was held in Amsterdam on 11-18 August 1990. This was a unique meeting in that it is the first time that the International Congress on Hyperbaric Medicine, the Undersea and Hyperbaric Medical Society, and the European Undersea Biomedical Society have come together to discuss issues in diving and hyperbaric medicine. There were over 450 participants from at least 40 countries, including members of more than 20 of the world's navies. The United States was by far the best represented.

The scope of the conference was broad, covering topics in hyperbaric oxygen (HBO) therapy, diving medicine, and basic sciences pertinent to both fields. Major papers were presented in plenary sessions attended by all. Because of the variety and number of papers presented (224 in all), often three sessions were held simultaneously. In addition, 100 papers were presented during four poster sessions. Presentations were generally limited to 10 to 15 minutes. Because of my recent introduction to this field, I found myself to be more a spectator than a participator. I tried to keep an open mind and learn where the research is currently focused and what directions it's taking. Being an undersea medical officer I focused primarily on the aspects of the meeting pertaining to diving; however, it was impossible to avoid entirely the issue of hyperbaric oxygen therapy.

HYPERBARIC OXYGEN THERAPY

HBO therapy grew out of the initial observations made by J. Cousteau that divers' wounds healed quicker at depth. Although not the first time in history this was observed, this was the trigger that set off a great deal of research into the possible medical benefits of breathing 100% oxygen at depth. In fact, wound healing is the one area in which scientific research has yielded unquestionable results. The initial success of HBO in wound healing resulted in a blossoming of HBO chambers and research trying HBO on any disease involving some sort of oxygen deficiency. Unfortunately, the majority of these attempts failed to show any additional benefits. This has resulted

in decreased funding and the field falling back onto the solid ground it established in wound healing, burns, and carbon monoxide poisoning. By focusing back on the successes, studying the etiology behind its successes, and obtaining information in a more scientific manner, the field has established a respectable status in medicine that it can now use as a foothold from which to work. This was reflected at the conference in the majority of papers, which focused on the successful uses of HBO, the etiology behind this, and the problems and logistics of HBO therapeutic chamber operations. The HBO sessions covered burns, toxicology/neurology, engineering, basic studies, and infection and wound healing. A separate instructional course on hyperbaric oxygen therapy was given. There were limited papers on obscure uses of HBO.

The majority of HBO treatment in the Far East is done in Japan, which has more than 200 chambers. Japan is joined by China, Taiwan, and Korea in a search for additional uses for HBO, but with little success. As in the West, the lack of success has resulted in decreased funding for research and treatment. Japan still appears to be looking for new and unique uses for HBO; however, it may soon be time for Japan also to look back to the successful uses before developing future HBO strategies.

DIVING MEDICINE

More time was dedicated to diving medicine at this conference than in the past, demonstrating an increased interest and participation in the field of diving medicine. Some of the major themes at the conference were: etiology and bubble formation, nervous system decompression sickness (DCS), physiology of diving/human performance, detection of bubbles, and deep diving. In addition, the conference concluded with an all-day workshop on data collection and analysis.

Etiology and Bubble Formation

It is well accepted now that bubbles are the underlying cause of decompression sickness. Type II DCS is attributed to intravascular bubbles and their secondary ischemic changes in tissues. Relevant data were supplied by Palmer (Wellcome Laboratory), who presented post mortem results of 25 cases of fatal diving accidents. The changes in nervous tissues were neither uniform nor specific for certain areas. The most common finding was perivascular lacunar formations, widely dispersed throughout white matter (18 of 25 cases). This supports the theory and data collected from animal studies (which were also presented at this conference).

In addition, Dutka (Naval Medical Research Institute) shed light on spinal cord DCS with a study in dogs. They combined somatosensory evoked potentials (SSEP) (currently the most sensitive technique at evaluating DCS) with video photography of animals surgically exposed immediately after rapid decompression. Diminished flow caused by bubbles in epidural veins directly preceded all SSEP changes. One animal without bubbles did not show SSEP changes.

Type I DCS etiology, though not as well understood, is felt to be mechanical in origin. Strauss (Long Beach Memorial Medical Center) proposed that the pathophysiology is due to distention of pain-sensitive structures, specifically the Ruffini Type II corpuscles. The next step should be to achieve additional supportive histologic data.

All this leads to a fairly good understanding of the mechanisms of DCS. As technology continues to improve and be applied to the hyperbaric environment, the finer details of DCS will be explained.

Decompression Sickness

The most severe form of DCS (which is often fatal) is Type II, neurologic DCS. The research into DCS focuses here. As noted previously, a great deal of information is available to us now on how it occurs. The other issues are prevention and treatment. Minor debates occur over depth, length of time, time of oxygen breathing, etc. However, the various treatment tables have survived relatively unchanged. Prevention focuses around safer diving and breathing mediums. Breathing oxygen and helium helps off gas and decreases the risk of DCS.

An approach to safer diving was discussed during the workshop. Also Nishi (Defence and Civil Institute of Environmental Medicine) presented the new Canadian dive tables, which are more conservative than the standard U.S. Navy tables.

The question asked of the attendees was, "What is an acceptable rate of occurrence of DCS?" A poll revealed responses ranging from none to 5-10%. There was no consensus. Because of the highly individual variability of DCS, to decrease the incidence to near zero must require extremely conservative tables as well as enormous efforts at prevention. I believe, however, that zero incidence is not an attainable goal. As more about how to limit and prevent DCS is revealed, people will merely respond by pushing the limits further. However, now that the pathophysiology and details of DCS are gradually being exposed, new adjuvant therapeutics as well as more meaningful changes in the treatment tables shall follow.

Physiology

There continues to be a strong interest in the effects of the hyperbaric environment on the individual, the physiologic response to diving, and how the individual performs at depth. Gas physiology is the most frequently studied, specifically, the narcotic effects of nitrogen and helium and the ability of divers to function under the influence of these gases. This is directly related to pulmonary physiology. Whether from depth or the increased partial pressure of oxygen, pulmonary function tests decline in saturation divers proportional to the length of exposure. This is mainly reflected in an individual's vital capacity, but has yet to be demonstrated in scuba. Another interesting effect is elevated liver function tests. Although the reason remains uncertain, liver enzymes are turned on during saturation diving. A diuresis also occurs at depth, multifactorial in nature, resulting in a significant decrease in plasma volume. Of course, the goal of looking at these various physiologic effects is to determine which may predispose to DCS and how to counterbalance the effect.

Lundgren (State University of New York at Buffalo) gave an interesting report on electrocardiogram changes in three Italian professional breath hold divers. Normal heart rates in the 60-80 beats/min range fell to one-third (20-28). There was marked sinus arrythmia and pVCs in all three divers and episodes of bigeminy in two. The bradycardia was depth related. Surface breath holds showed a time related bradycardia to the 30-40 beats/min range.

A controversial debate exists on whether screening should be conducted for cardiac shunts. Wilmhurst (St. Thomas' Hospital, London) suggested that an early neurologic presentation of DCS is significantly higher in divers with a right to left intra-atrial shunt, while other presentations show equal incidence. However, the incidence of shunts in the general population is 25%. Thus, the jury is still out on whether screening should be conducted and just what changes would come about as a result.

Detection of Bubbles

After diving, bubbles can be detected in the circulation via Doppler and the more sophisticated M-mode ultrasonic methods. A number of papers pertained to these now well established techniques. Correlation has been repeatedly shown between the severity of bubbles and the incidence of DCS. One illuminating study that involved bubble detection was presented by Ikeda (Japan Maritime Self-Defense Force). Three groups of saturation divers were kept at 6, 7, and 8 meters for 3 days and decompressed at 1 m/s. One of 10 divers showed bubbles at 6 meters, 4 of 10 divers showed bubbles at 7 meters, and all divers at 8 meters experienced a significant occurrence of bubbles. Four of nine divers at 8 meters were treated for decompression sickness. This demonstrates that the risk of DCS begins at depths greater than 7 meters.

Bubble formation correlates with DCS, but there is no predictive value in bubble detection. All papers reinforced this. Little progress has been made here and the search continues for a way to predict whether an individual will develop DCS.

Deep Diving

Many oil drilling and mining opportunities exist at depths greater than we can currently reach. A number of countries are involved in deep diving research. The French, who seem to be conducting the leading research, presented their ongoing data. Depth capabilities are currently limited by the narcotic and central nervous system effects of the breathing medium (a helium and oxygen mixture).

The major disease preventing deep diving is high pressure nervous syndrome (HPNS). It is apparently related to pressure dependent dopamine release. The technology now exists to study neurotransmitter behavior at the synaptic level, not only at depth but during the compression phases of a dive. A more complete understanding of HPNS should result from this research.

The latest results from the COMEX Hydra research program, which is exploring the use of hydrogen gas, were presented (Hydra IX). In the first study, a hydrogen and oxygen mixture was used. Divers were gradually compressed to 300 meters. At 240 meters electroencephalographic changes occurred. At 300 meters tremors occurred, and two of the three divers experienced psychotic disorders. Thus, the upper limit of hydrogen use is no more than 24-25 bars. In addition, adding hydrogen to the helium/oxygen mixture suppressed the tremors of HPNS experienced at 300 meters. In the second study, the long-term effects of using a hydrogen/helium/oxygen mixture (hydreliox) were examined. The prior maximum depth attained was 530 meters. Researchers found no long-term effects and a significant increase in diver control without narcosis (30-day duration). By maximizing all three gases, diving to between 500 and 700 meters is now possible.

These depths are greater than most have expected. With continued research and the inclusion of a greater variety of gases, the absolute working depth man can attain has yet to be determined, but it may exceed 800 meters.

Data Collection and Analysis

The thrust of this workshop was to discuss ways of collecting data about diving accidents in more detail so that accurate databases can be established. Many existing databases were presented. It was obvious that no one database would be effective. Recreational and commercial diving are so different that they must be approached separately.

The Divers' Alert Network (DAN) is the most extensive recreational network established. This group presented the results of the information collected during the previous

year. DAN members are now facing the problem of getting more precise information about the diving profiles of accidents. This is hampered by poor reporting and confusion at the time an accident occurs. While the forms they use must be simple and easy to fill out so that people will comply, the forms must also be as thorough as possible if they are to be of greater value. The farther away a diving accident occurs, the more difficult it is to obtain the information about it, and much diving takes place in remote areas. As existing databases increase in experience, and more and more databases are established, interaction should also increase, resulting in an amassing of information surrounding diving accidents. This, in turn, should mean that such information will be of increasing usefulness.

The major problem with commercial diving accidents has been the complicated nature of the dive profiles, which is often aggravated by a great reluctance to accurately report the circumstances surrounding accidents. Most of these reports are deliberately falsified for legal and financial reasons. Simple depth time logging is not enough if alterations in decompression schedules remain unrecorded. Individuals are reluctant to report accidents or deviations from schedules for fear of pay being docked or careers being ended for medical reasons. This problem is ubiquitous, as described in Scandinavia, Europe, North America, and Asia. A depth time profile recorder would alleviate the problem of inaccuracies. The Saitama dive profile recorder has been a valuable tool in Japan and the United States for a number of years, but it is a bulky apparatus. However, the technology now exists for compact mechanical dive depth recorders. Contractors in the North Sea are beginning to require such recorders for insurance purposes.

A new problem is that others, wary of data collection, are now using the data for their own purposes. For example, lawyers are obtaining DAN information for use in subpoenas. Employers could use the information against the divers (spying). And the information from the recorders is only obtained following completion of the dive, and thus is of little use in designing the individual's decompression schedule. What is needed is real time nonpunitive data collection. The need for this has been recognized for many years, but now the technology to realize this is around the corner. On-line time depth recording provides accurate records, evidence of responsibility, and cumulative analysis of performances, as well as encouraging compliance. Once this technology has been realized, mandatory international data collection can begin that will yield data to improve diving operations and dive tables without punishing the individuals involved in the diving.

THE FAR EAST

Hyperbaric medicine research in Asia is being conducted primarily in Japan because of the funding involved. Diving medicine in Japan now has two major centers: the Japan Maritime Self-Defense Force Undersea Medical Center, which receives funding from the Japanese Government's defense budget, and the Japan Marine Science and Technology Center, which receives Government funds designated for scientific research. In addition, excellent work is being done by the Underwater and Hyperbaric Medicine Department of Saitama University's Medical School. These groups will ensure that Asia continues to contribute significantly to undersea medicine.

Undersea medicine is by no means limited only to Japan. Many other Asian countries are becoming involved in diving medical research, which can only mean that hyperbaric chambers and diving programs are already in place, and funds are being set aside to conduct research. Those countries with representatives at this conference included China, Taiwan, Korea, and Singapore. There has always been strong

interest in diving medicine in Australia and New Zealand, which also influences the field in Asia.

In addition to research, the amount of recreational diving in Asia has skyrocketed. The South Pacific offers numerous islands and reefs and is one of the most popular vacation sites for divers. Diving has become very popular in Japan as well, where novice divers are the most common victims of diving accidents. No database exists to evaluate the accidents. There is a definite need here for more close monitoring of diving activities.

CONCLUSION

The last question one must ask is, "Why does such a strong interest in diving medicine persist, and where will it focus in the future?" The answer lies both in recreational and commercial diving. The cost of recreational diving is now reasonable enough that most interested people can experience it, thus explaining the drive for increased safety and monitoring of recreational diving.

In commercial diving there is a need for increased safety and monitoring to prevent serious complications. The future will lead to increased research towards deeper diving, since the ocean floor hides a vast amount of natural resources. The situation in the Middle East shows us just how unreliable our fuel supplies can be, and moderate increases in prices will make mining oil from deeper levels profitable. This will necessitate deeper diving capabilities. No one is more aware of this than the Asian countries that rely so heavily on the Middle East for oil.

Diving medicine will also play an integral role in our future in space. Weightless training occurs in water, and the new NASA weightless trainer that is currently under construction will be a large lake at least 60 feet deep with built-in exit platforms at depth. In addition, hyperbaric treatments have been deemed essential to space station operations. The numerous operations under pressure in space incorporate a risk of rapid decompression and a need for recompression therapy.

The bright future of, and thorough commitment of researchers to, hyperbaric medicine was demonstrated at this conference. Continued research into the effect of the hyperbaric environment on human physiology, and etiology and treatment of hyperbaric diseases, allows us to strive for the extreme depths and heights our world has to offer.

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THE ROYAL AUSTRALIAN NAVY SCHOOL OF UNDERWATER MEDICINE

Neal Naito

The School of Underwater Medicine located in Sydney was founded in 1963. It is the Royal Australian Navy's only center for diving and submarine related medical research and education. Although much smaller than comparable military undersea research facilities in the United States and Japan, its commitment to doing applied research even with limited resources has enabled the school to still make significant scientific contributions to the field of undersea medicine. Some interesting current and proposed research projects include screening of diving candidates for training on underwater rebreathing apparatuses and emergency removal of carbon dioxide from submarines.

INTRODUCTION

The School of Underwater Medicine (SUM) located in Sydney is the Royal Australian Navy's (RAN) center for diving and submarine related medical research and education. It was founded in 1963 under the direction of the then Medical Director General of the RAN, Surgeon Rear Admiral Lionel Lockwood. During this period, the training of divers was expanded due to the increased availability of free swimming underwater breathing apparatuses. Subsequently, it was recognized that there would be a need for physicians specifically trained in undersea medicine, both as clinicians and researchers. The first officer in charge (OIC) of the school was Surgeon Lieutenant Commander (SURG LCDR) Rex Gray, RANR. Prior to becoming OIC, he spent several months in Britain and the United States visiting diving research facilities to become familiar with the latest developments in the field.

Up until about 1967, the main focus of the school was on instruction of medical officers during a 2-week course. With the arrival of SURG LCDR Carl Edmonds, research at SUM assumed a higher priority. A psychiatric specialist, Dr. Edmonds was OIC at SUM from the late 1960s to the mid 1970s. It was during his time at SUM that he wrote the authoritative reference *Diving and Sub-Aquatic Medicine* along with two other staff members.

PERSONNEL

In regards to current personnel at SUM, there are two medical officers, the OIC SURG LCDR Michael Loxton and SURG LCDR Kevin Boundy. Medical officer tours at the school are 2 years with the possibility of a 1-year extension. This frequent turnover tends to be a handicap to long-term research projects. In contrast, the science and technical officers are civilians and have been at SUM for many years. John

Pennefeather, a coauthor of Edmond's reference text, is the science officer and provides the basic science and engineering expertise. Frank Blackwood is the technical officer and is involved in maintaining and building the electrical and mechanical equipment used in research projects. Since staffing is limited, the school has taken the novel approach of having the technical officer trained to do many tasks. Besides being a skilled electronic repairman, metalworker, and woodworker, he is also a capable audiology and electroencephalogram (EEG) technician. Other members of the staff include an administrative officer, a librarian, a secretary, and nine enlisted sailors. Figure 1 shows the author with some of the staff.

Figure 1. The staff of SUM. From left to right, John Pennefeather, SURG LCDR Michael Loxton, the author (camouflage wear), and SURG LCDR Kevin Boundy.

FACILITIES AT SUM

All the staff of SUM work out of waterfront facilities at HMAS Penguin amidst the RAN Diving School. Other commands on the base include the EOD School; the Staff College; the Hydrographic School; the Nuclear, Biological, and Chemical Defense School; and a surgical hospital. The facilities consist of two adjacent buildings with one housing the recompression chamber and the other the school itself. The latter is an 11-room structure that contains four offices, three laboratory spaces, a medical treatment room with full emergency cardiac resuscitation capability, a classroom, and a library. The library is small but adequate. It contains an extensive collection of articles on diving medicine and subscribes to approximately 80 periodicals covering mainly underwater medicine, general medicine, and general naval subjects. The number of bound volumes is small, but the library participates in a defense interlibrary loan program that allows for access to a much larger collection. Titles are available on microfiche, which are updated on a regular basis.

Moving from the library to the laboratory, again inventory is small but sufficient. Equipment includes a mass spectrometer, EEG recorder, CO_2 analyzer, impedance audiometer, experimental animal hyperbaric chamber, pulmonary function analyzer, and general purpose oscilloscopes. Computer support consists of Apple personal computers with an IBM PC-386 on order. Work space seems to be adequate.

The recompression chamber center houses a 10-man double compartment chamber (see Figure 2). It was opened in 1985 at a cost of $4 million (Australian). Depth limit is 205 meters, and it can accept either air, oxygen, Nitrox, or helium gas mixtures. The chamber environment is monitored and controlled for humidity, temperature, carbon dioxide, and oxygen. Inside monitoring of personnel is accomplished via closed circuit TV. Placement of inside EEG monitoring capability is planned for the future, while electrocardiography (EKG) is already available. A medical lock and an integrated fire fighting system are also present. A saturation dive to 90 meters for 7 days has been done. No further dives are scheduled since the RAN does not possess a saturation diving system.

FUNCTIONS OF SUM

The location of SUM allows it to carry out efficiently its primary mission of supporting the dive school through screening of diving candidates, direct primary care of staff and trainees, and 24-hour response to diving emergencies. On average, SUM treats three cases a month of mainly decompression sickness. Arterial gas embolus (AGE) comprises about six cases a year. The overwhelming majority of the patients are civilian recreation divers. Another tasking, training in underwater medicine, has expanded to include a month-long physician course and a 6-month diving medicine technician (DMT) course. Both are held only once a year.

The physician course instructs military and civilian doctors as to the clinical fundamentals of treating the wide spectrum of diving illnesses and is similar in scope to the 3-week U.S. Navy class taught in Panama City, Florida. Only just recently started, the DMT class is open to qualified Navy and Army medics and is comparably comprehensive as the equivalent U.S. Navy program. There is more emphasis on acute care medicine as the teaching of advanced cardiac life support and a 2-week practicum at a Sydney hospital emergency room (ER)

are included. Graduates are expected to operate with clearance diving teams independent of a medical officer and provide complete routine and emergent care to attached personnel.

Due to a limited research operating budget at SUM ($40,000 for fiscal year 1990), projects are practical in nature. Some interesting ongoing andproposed investigations include screening of diving candidates for usage of Drager LAR V or FGT underwater rebreathing apparatuses, possible development of a more efficient air circulating pump for an emergency manpowered CO_2 scrubber system aboard submarines, collection of data on the treatment of arterial gas embolus by using 18-meter O_2 tables, and starting a diving accident registry.

During the in-water training phase of a diving class, up to 20% of the trainees may experience symptoms such as blackouts when breathing with the Drager LAR V or FGT. Studies by SUM staff have shown that in addition to those symptomatic students who are CO_2 retainers, there exists another group that exhibits large fluctuations in resting minute volume when given a CO_2 provocation test of different concentrations. Thought to be a delayed or disordered response to the test, these findings possibly suggest the loss of some respiratory controlling chemoreceptors. Current policy is to drop students with abnormal test results who have become symptomatic on the rebreathing rigs.

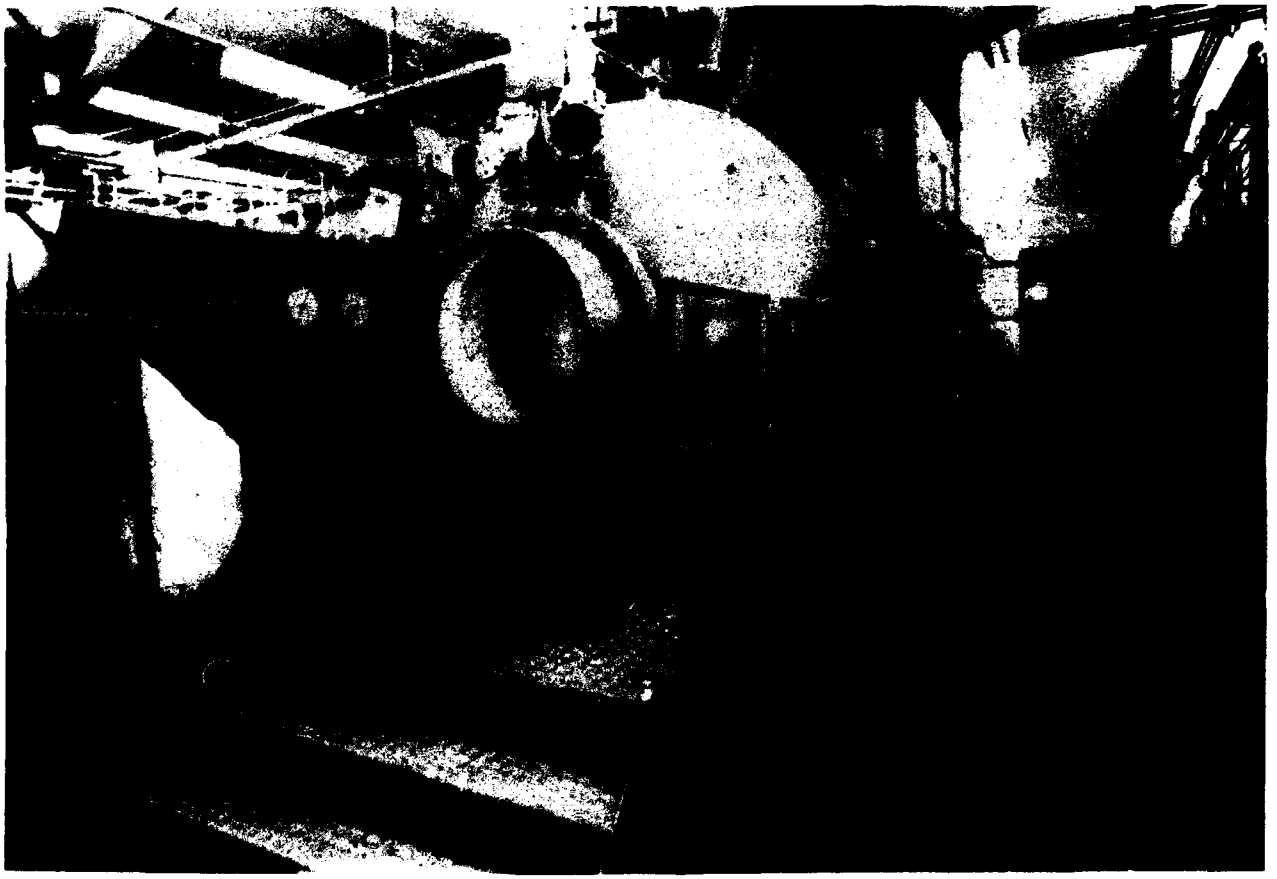

Figure 2. Inside of recompression chamber center.

With a new class of submarines being built for the RAN, SUM staff have been doing informal exploratory work examining backup systems for removal of CO_2 during an emergency. Current approaches include electrical and air motor based designs. Limitations include battery duration and undesirable increases in submarine ambient air pressure leading to decompression sickness. Improving on a British device, a foot-operated, two-cylinder, double-acting pump is being evaluated by SUM investigators as an alternative.

For the past several years, data have been reported that seem to indicate maximum depth O_2 tables are more efficacious in the treatment of AGE. SUM is going to treat all cases of AGE with an 18-meter O_2 table and compare results with previous protocols employing 50-meter air tables. Finally, there is no registry presently set up in Australia from which to gather data on diving accidents similar to those in America operated by the civilian organization Diver's Alert Network or the U.S. Navy Safety Center. SUM is in the process of organizing one for its cases. SUM's proposed and current research projects are as follows:

Proposed New Research Projects

1. Emergency removal of carbon dioxide from submarines
2. Factors affecting performance of carbon dioxide scrubbers
3. Evaluation of options for purchase of a new clearance diving breathing apparatus to replace the Drager FGT rig
4. RAN diving accident registry

Current Research Projects

1. Neurological sequelae of dysbaric illness
2. Energy expenditure during swimming
3. Assistance with evaluation and purchase of replacement two-man recompression chambers
4. Oxygen-helium diving
5. An emergency oxygen delivery system for use aboard submarines
6. 18-meter oxygen table for the treatment of AGE
7. Responses of diving candidates to inhaled carbon dioxide
8. Lung function in clearance divers
9. Underwater noise hazards of sonar and tools
10. Evaluation of screening tests for selection of diving school candidates
11. Development of a new treatment protocol for saltwater aspiration
12. Skeletal sequelae of dysbaric illness

To increase opportunities for research at SUM, joint projects with civilian universities have been considered. However, university budgets are similarly constrained. Moreover, there is a dearth of civilian hyperbaric researchers in Australia.

CONCLUSION

SUM is a small but highly capable unit within the RAN and can be expected to continue its history of contributions to the understanding of undersea medicine. Contact can be made by writing to the following address: OIC SUM, HMAS Penguin, Balmoral NSW Australia 2091.

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A VISIT TO THE JAPAN MARINE SCIENCE AND TECHNOLOGY CENTER'S SATURATION DIVING RESEARCH VESSEL Kaiyo

Neal A. Naito and Cameron A. Gillespie

The Kaiyo *is a unique, twin-hulled, saturation-diving-capable research vessel owned by the Japan Marine Science and Technology Center. Operating since 1985, it contains many advanced design features that allow it to carry out additional missions besides saturation diving, including deep ocean mapping and launch and recovery of remotely operated vehicles. During a recent at-sea saturation dive, the authors were invited to visit the ship and report on its activities.*

INTRODUCTION

The Japan Marine Science and Technology Center (JAMSTEC) is the primary institution in Japan dedicated to ocean research and development (Ref 1). It was established in 1971 and is funded jointly by government, academia, and private industry. Located at its present site since 1973, JAMSTEC is situated in the bayside city of Yokosuka, approximately 1 hour south of Tokyo by train.

The JAMSTEC campus is very spacious and contains docking facilities for its three research vessels, the *Natsushima*, the *Yokosuka*, and the *Kaiyo*. The *Natsushima* and the *Yokosuka* are support ships for the deep sea submersibles *Shinkai 2000* and *Shinkai 6500*, respectively. The *Kaiyo* is the sole saturation diving vessel for JAMSTEC and one of the most advanced in the world.

THE U.S.-JAPAN COOPERATIVE PROGRAM IN NATURAL RESOURCES

Through the efforts of Gregory Stone, an American guest researcher at JAMSTEC, the authors spent 2 days during July 1990 aboard the JAMSTEC ship *Kaiyo* to observe part of a 12-day at-sea saturation diving operation. On exchange from the National Oceanic and Atmospheric Administration's (NOAA) National Undersea Research Program, Mr. Stone is also a member of the Panel on Diving Physiology and Technology of the U.S.-Japan Cooperative Program in Natural Resources (UJNR), under whose auspice the authors' visit was arranged.

Established in 1969, this UJNR panel has been one of the most active, holding joint meetings every 2 years. The purpose of the program is to encourage meaningful

cooperation between the two countries through bilateral scientific projects, the exchange of scientists, and the sharing of data or technology. Many JAMSTEC personnel from the Diving Science and Technology Department participate on the panel.

DIVING SCIENCE AND TECHNOLOGY DEPARTMENT RESEARCH PERSONNEL

During their visit to the *Kaiyo*, the authors met several of the key researchers from the department. The executive director of the department is Mr. Nakano, who has a B.A. in engineering from Kobe University. The research supervisor of the department is Mr. Aoki, who received a B.S. in naval architecture from the National Defense Academy. Within the department, researchers are assigned to groups, each with their own different projects. The authors met Dr. Ito, senior scientist of group 1, who has a Ph.D. in agriculture from Tokyo University; Dr. Okamoto of group 2, who graduated from Hokkaido University with a Ph.D. in fisheries; Mr. Yamaguchi, also of group 2, with a B.S. in naval architecture from Yokohama National University; Dr. Mohri, senior scientist of groups 3 and 4, who earned an M.D. from Yokohama City University; Dr. Naraki of group 3, who completed his general science Ph.D. at the University of Marseille; and Mr. Taya of research group 4, who has an M.S. in agriculture from Nihon University.

GENERAL FEATURES OF THE *Kaiyo*

Commissioned in 1985, the *Kaiyo* has the following specifications:

Length	61.5 meters
Width	28 meters
Depth	10.6 meters
Gross tonnage	2,849 tons
Cruising speed	13.2 knots
Crew size	29
Research personnel	40

Its semi-submersible twin-hull design allows for increased at-sea stability and a large deck work area. Figures 1 and 2 show the exterior of the ship and its general layout. The ship can operate safely up to a Beaufort scale sea state three. Other capabilities include launch and recovery of remotely operated submersibles and deep ocean floor mapping to 11,000 meters using a multi-narrow beam depth sounder. Noise abatement features to enhance the use of onboard acoustic equipment include an electric propulsion system and isolation of as many noise sources on deck above the water.

To remain stationary during an open-sea saturation dive, the *Kaiyo* was built with a conventional four-point mooring system useful to a depth of 100 meters. Additionally, the *Kaiyo* has a dynamic positioning system that incorporates a computer tracking system that continuously maintains the ship's location using either signals transmitted from land or from deployed transponders. The actual placement of the ship is maintained by bow and aft thrusters on both hulls along with twin screws. This configuration also allows the *Kaiyo* to make a 360-degree turn along a vertical axis. In contrast, U.S. Navy saturation diving ships can do only a four-point moor.

Living conditions aboard the *Kaiyo* for the crew and researchers are quite good. Rooms are functionally appointed with beds,

desk, sink, and lights. No more than two people have to share quarters. Traditional Japanese food is usually served aboard at meals and is of restaurant quality. A small sickbay is available for the treatment of minor medical problems.

THE *Kaiyo* SATURATION DIVING SYSTEM

The saturation diving system onboard the *Kaiyo* consists of two deck decompression chambers (DDC) and two submersible decompression chambers (SDC) all rated to 300 meters. Each DDC can accommodate up to six men while the SDC can hold three men. The two deck decompression chambers are connected to a middle chamber where men can be transferred to a SDC. From the SDC divers can make excursion dives in the ocean. To lift the SDC from where the divers have transferred from the middle chamber over to the central well for lowering into the ocean, the *Kaiyo* is equipped with an A-frame crane in the middle of the deck. Two other A-frame cranes are on the starboard and aft side of the ship. The aft crane is used to launch submersibles while the starboard crane can lower the second SDC or other projects.

Monitoring of divers in the SDC and the ocean via closed circuit television (CCTV) and direct voice communications is done on the third deck at the main control console. Once the divers return to the DDC, they are monitored by personnel stationed at the adjacent chamber control console. At this console, divers in the chamber can be continuously observed by CCTV. Also, the chamber environment is closely monitored for gas mixture composition, O_2 level, CO_2 level, humidity, and temperature.

Figure 1. The *Kaiyo*.

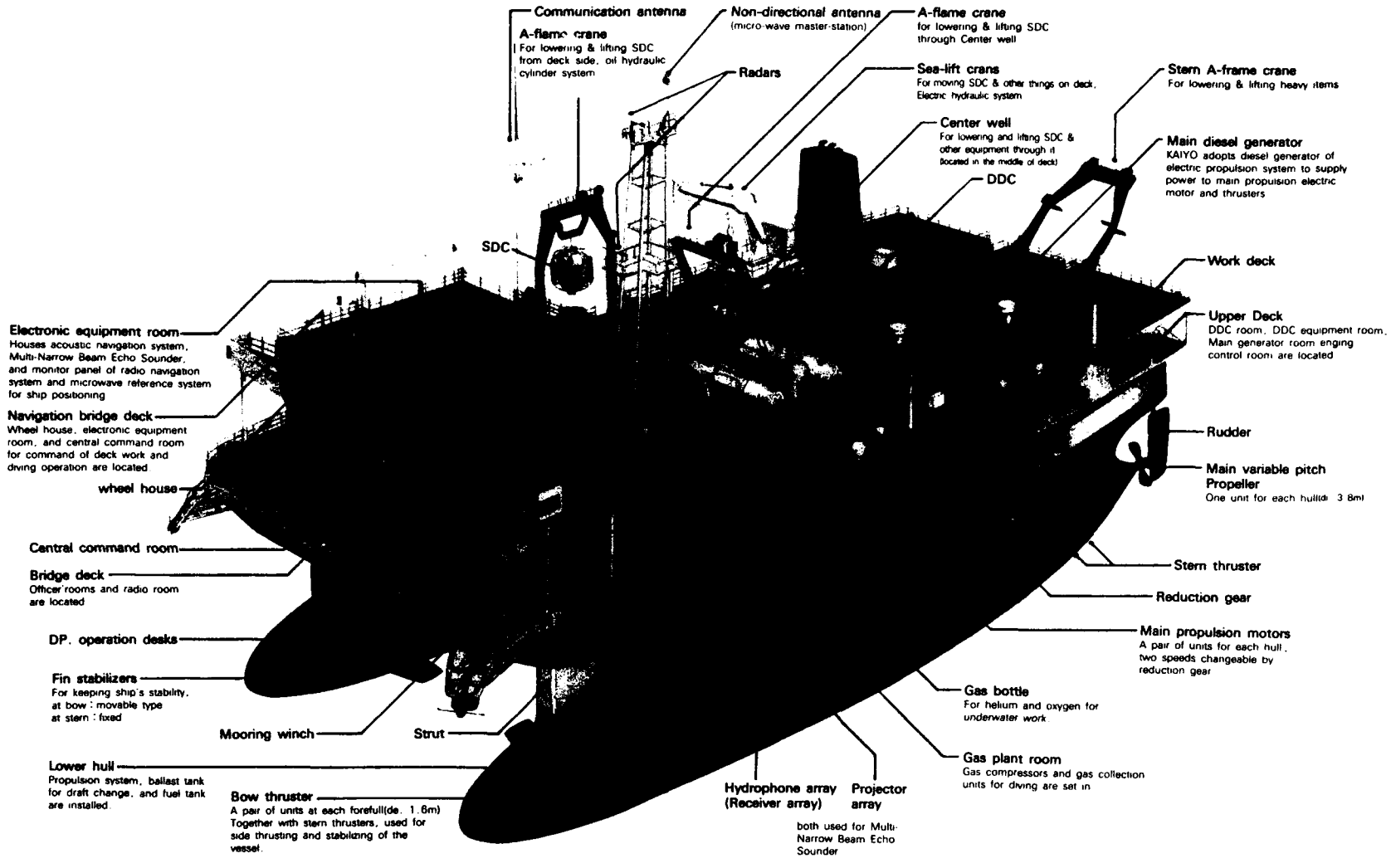

Figure 2. General layout of the *Kaiyo*.

Gas mixtures that can be used in the system include air, oxygen, nitrogen/oxygen, helium/oxygen, and a tri-mix of the three gases. Helium/oxygen is the breathing medium most often used in deep saturation dives since it has no narcotic effects as with nitrogen, and it has good decompression profile characteristics. In the DDC, gas mixtures can be modified continuously, while in the SDC and the divers helmet it remains constant.

The helmet JAMSTEC divers use is a commercially available Superlite 17 constructed out of fiberglass and modified for a recirculating push-pull system (see Figure 3). This system allows reclamation of expiratory helium from the diver, which is "pulled" back to the ship rather than vented to the environment. On the ship, it is then remixed with oxygen and "pushed" back to the diver. Since helium is imported and consequently expensive in Japan, recycling becomes cost effective. CO_2 is removed from the diver's exhaust by passing it through a soda lime canister contained in a backpack the diver wears. The divers are also thermally protected with hot water suits which use heated saltwater pumped down from the *Kaiyo* as the ocean temperature at 300 meters can be very cold.

Figure 3. Superlite 17 dive helmet configured for "push-pull" system.

NEW SEATOPIA

Since 1985 JAMSTEC has been conducting both an open-ocean and shore-based simulation saturation dive annually under the project name New Seatopia. The original Seatopia project was conducted from 1972-75 and involved divers living in an underwater habitat at a depth of 100 meters. It was patterned after the Sealab experiments conducted by the U.S. Navy in the late 1960s. Between 1975 and 1985 JAMSTEC continued its saturation diving experiments under the designator Sea Dragon. During this period, the maximum depth reached was 300 meters with a maximum duration of 14 days.

The purpose of New Seatopia is to continue investigations begun under Seatopia and Sea Dragon into the physiological and psychological effects a high pressure environment has on man (Ref 2). The majority of this work has been done in the controlled environment of the shore simulation facilities where hook-up of divers to sophisticated recording and testing devices is much easier than in the open ocean. Furthermore, this project provides the opportunity to get operational experience conducting an actual saturation dive at sea.

For the phase of New Seatopia that the authors observed, the maximum depth reached was 300 meters. At 300 meters, the helium-oxygen mixture was 98% and 2%, respectively. Total dive time for team A was 20 days, team B 17 days, and team C 16 days. See Figure 4 and Tables 1-3 for complete dive profile and characteristics.

RESEARCH CONDUCTED DURING SATURATION DIVE

JAMSTEC researchers were primarily interested in continuing their evaluation of remote electrocardiograph (EKG) monitoring of divers in the water and the use of a remotely operated vehicle (ROV) to directly visualize them as procedures to enhance the safety of open water saturation diving (Ref 3). It was also desired to examine the visual tracking ability of divers at the working depth of 300 meters.

The remote EKG tracings obtained from the divers were of marginal quality due to interference generated by their movement and would only allow one to distinguish gross differences between tracings. Findings such as asystole, ventricular tachycardia, ventricular fibrillation, or premature ventricular contractions could be differentiated from a regular rhythm. It would not be possible to discern relatively fine detail such as elevated ST segments or heart block. However, even this limited capability would be very useful in assessing a suddenly symptomatic working diver.

The JAMSTEC ROV *Hornet* provided excellent visualization of the divers while they were in the water. Weighing 59 pounds and having a cruising speed of 2.5 knots, the *Hornet* system consists of the vehicle, a control/monitor console, a primary cable incorporating optical fiber communication lines, a neutrally buoyant secondary cable, and a launch/recovery stage. The authors were allowed to operate the ROV and found it to be easy to use and highly maneuverable. With an operating depth of 500 meters, the JAMSTEC ROV *Hornet* has a primary mission of geological and biological surveying (see Figure 5).

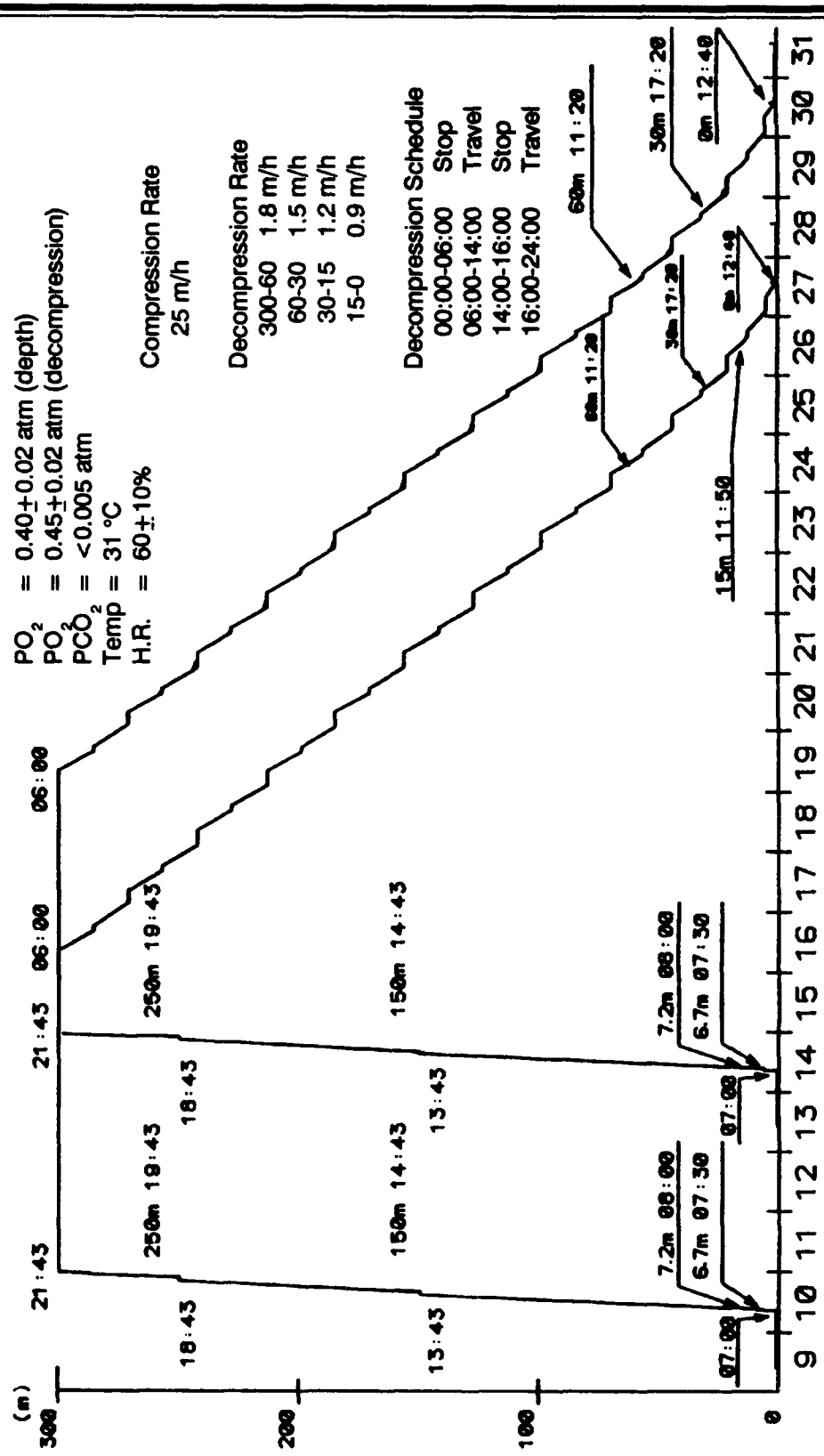

Figure 4. Three hundred meter saturation dive profile.

Table 1. Oxygen and Carbon Dioxide Levels During Dive

Stage	Level (atm)	
	PO_2	PCO_2
Surface	0.21	<0.005
300 Meters	0.40	<0.005
Decompression	0.45	<0.005

Table 2. Emergency Breathing Gas Mixture at Various Depths During Dive

Depth (m)	Concentration (%)	
	He	O_2
0-60	84	16
60-120	95	5
120-300	97	3

Table 3. DDC Environmental Conditions During Dive

Stage	Temperature (°C)	Relative Humidity (%)
Surface	26.0	60
Compression	26.0-31.0	60
300 Meters	31.0	60
Decompression	26.0-31.0	60

In regards to the visual tracking experiment, the testing device was a part of a platform lowered to the ocean floor that contained other materials and objects the diver would use in various tasks during the excursion dive. The device consisted of two identical stations with a steering wheel and a meter containing two pointers above it. One of the pointers moved randomly while the other pointer was controlled by the steering wheel. The intent of the test was for the diver to match his pointer to the randomly moving one by using the steering wheel. Results would be tabulated by a computer link-up. Previous studies performed at 200 meters revealed no detectable impairment of visual tracking. Results from testing at 300 meters were not available at the time of the authors' visit.

CONCLUSION

The *Kaiyo* is a highly capable saturation diving ship and one of the finest in the world. A ship of similar design and capabilities built for oceanographic research is being contemplated by the U.S. scientific community. The Diving Science and Technology Department has many experienced researchers and technicians who can direct and conduct the most demanding saturation dive operations. However, in discussions with department members, the authors learned that the saturation dive they observed marked the end of the New Seatopia project with no further ocean dives scheduled for the foreseeable future. It is the authors' conjecture that since Japan is a relative newcomer to deep sea exploration, the quickest way to overcome this inexperience would be to tap its lead in applied robotic technology. With the success of the JAMSTEC manned and unmanned submersible program, the benefit of continuing a full research program in saturation diving including ocean operations is not clear. Moreover, unlike Europe and the United States, Japan does not have any appreciable offshore oil industry, which is a large commercial user and supporter of saturation diving. Militarily, the Japanese Maritime Self-Defense Force has its own saturation diving vessel, shore

simulation facility, deep submergence rescue vessel, and research program for the purpose of submarine rescue.

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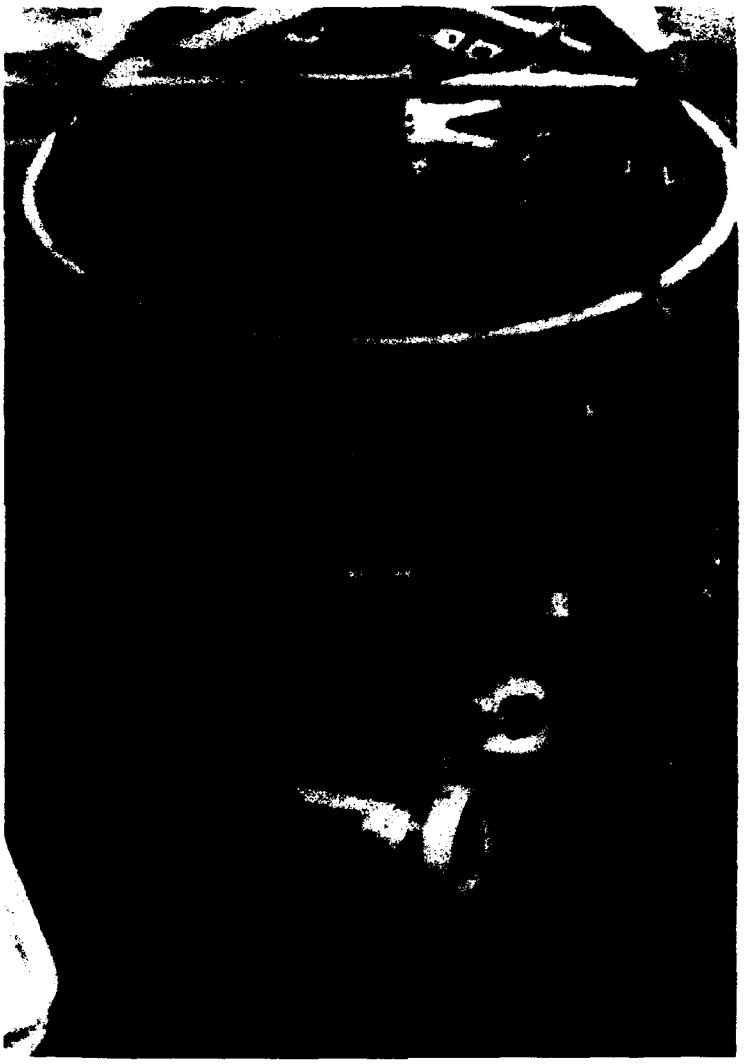

Figure 5. ROV *Hornet*.

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